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(54) **TOUCH-BASED USER INTERFACE WITH HAPTIC FEEDBACK**

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CPC ..... **G06F 3/016** (2013.01); **G06F 3/03547** (2013.01); **G06F 3/041** (2013.01); **H01L 41/0986** (2013.01); **H01L 41/37** (2013.01); **Y10T 29/42** (2015.01)

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See application file for complete search history.

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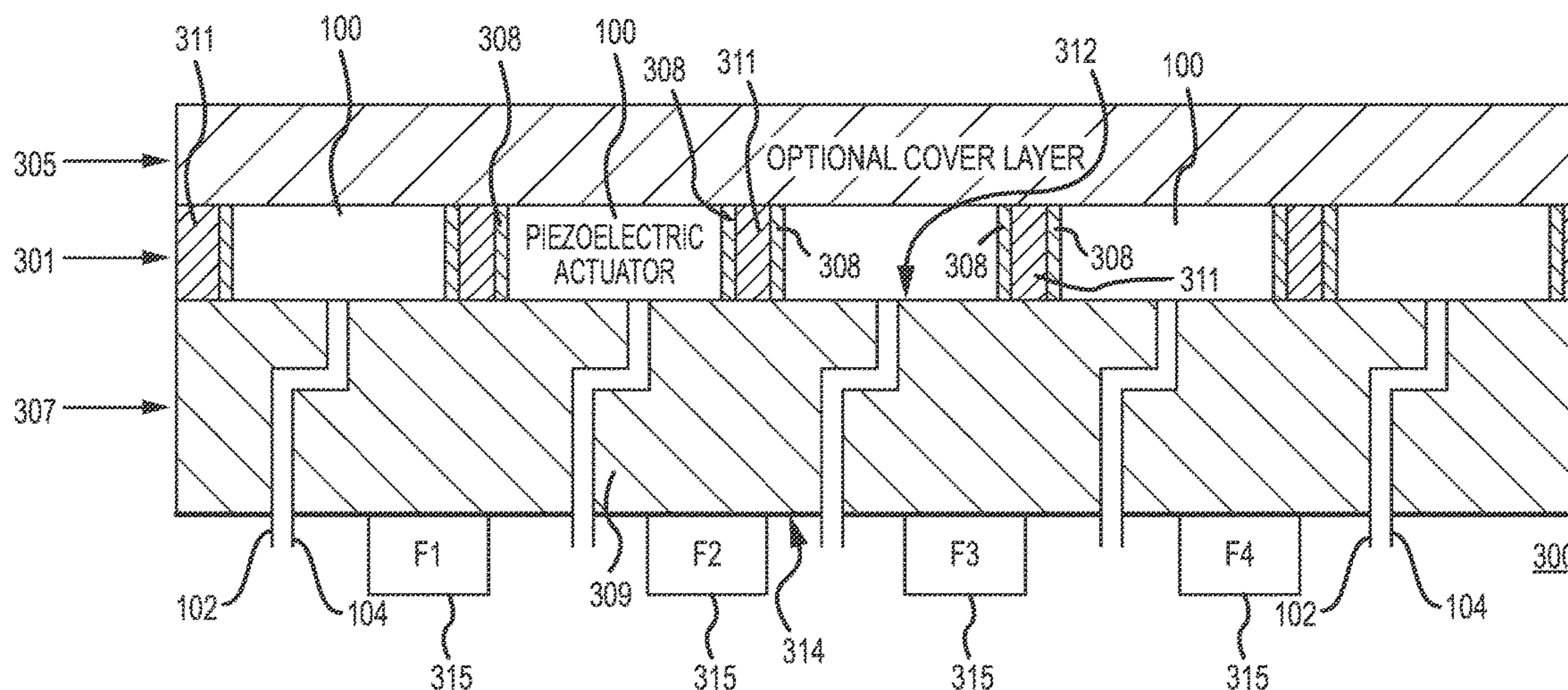
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(57) **ABSTRACT**

One embodiment of a touch-based user interface may include a haptic feedback layer with one or more actuators configured to supply a haptic feedback. The one or more actuators may be embedded in a nonconductive material. The touch-based user interface may further include a printed circuit board layer underlying the haptic feedback layer. The printed circuit board layer may include one or more conductive traces configured to supply a voltage to the one or more actuators.

**20 Claims, 19 Drawing Sheets**



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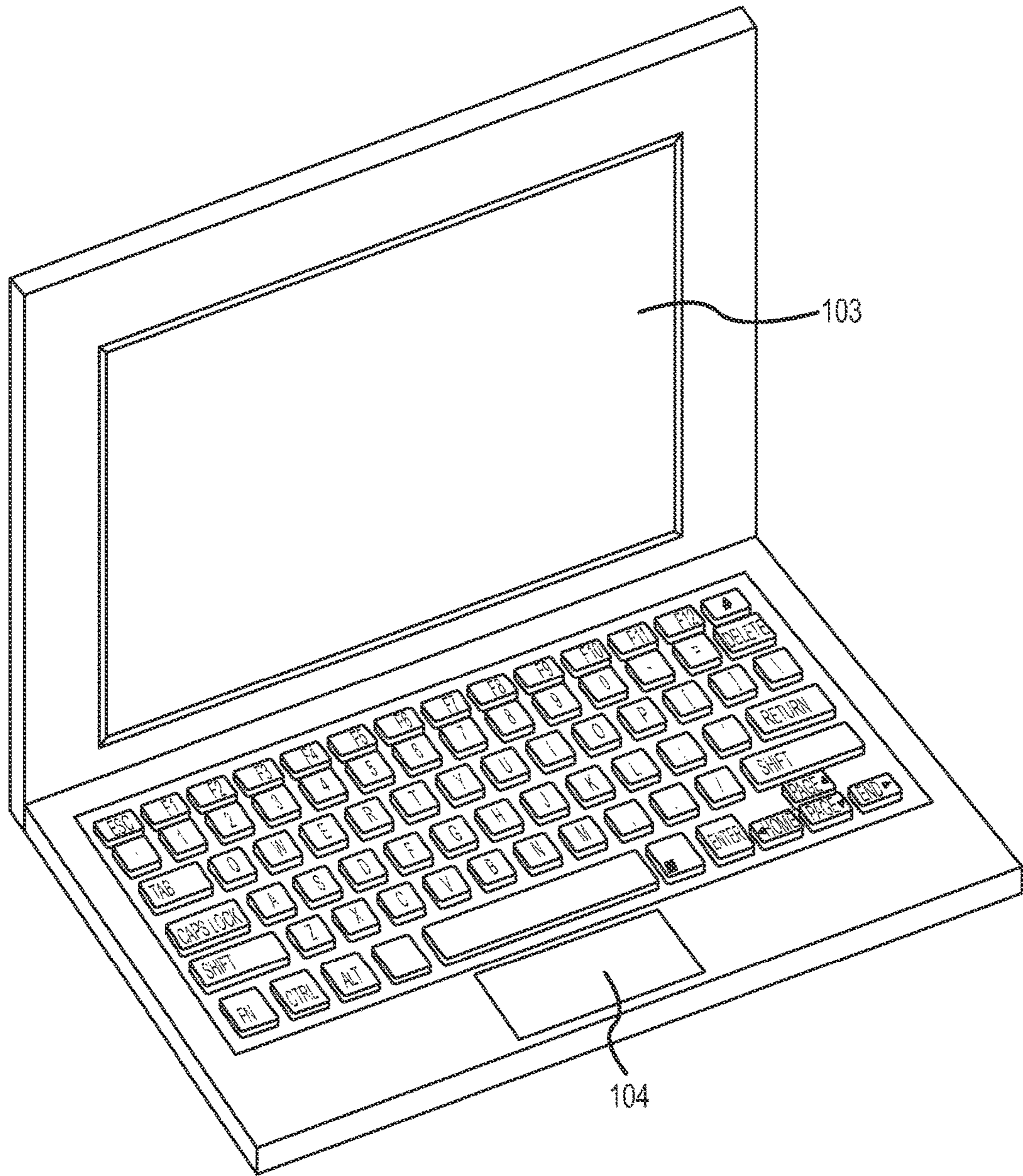
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FIG. 1A

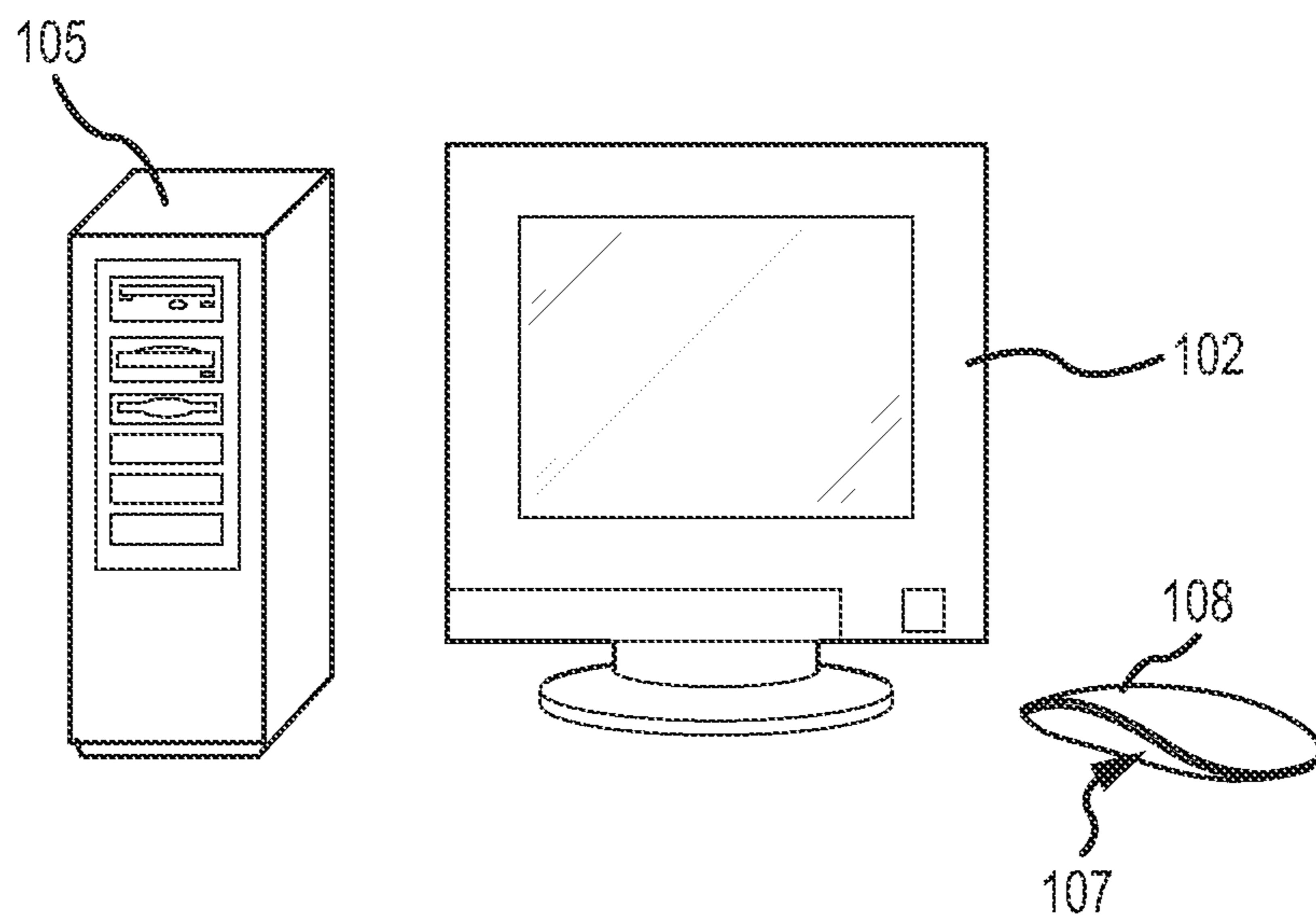


FIG. 1B

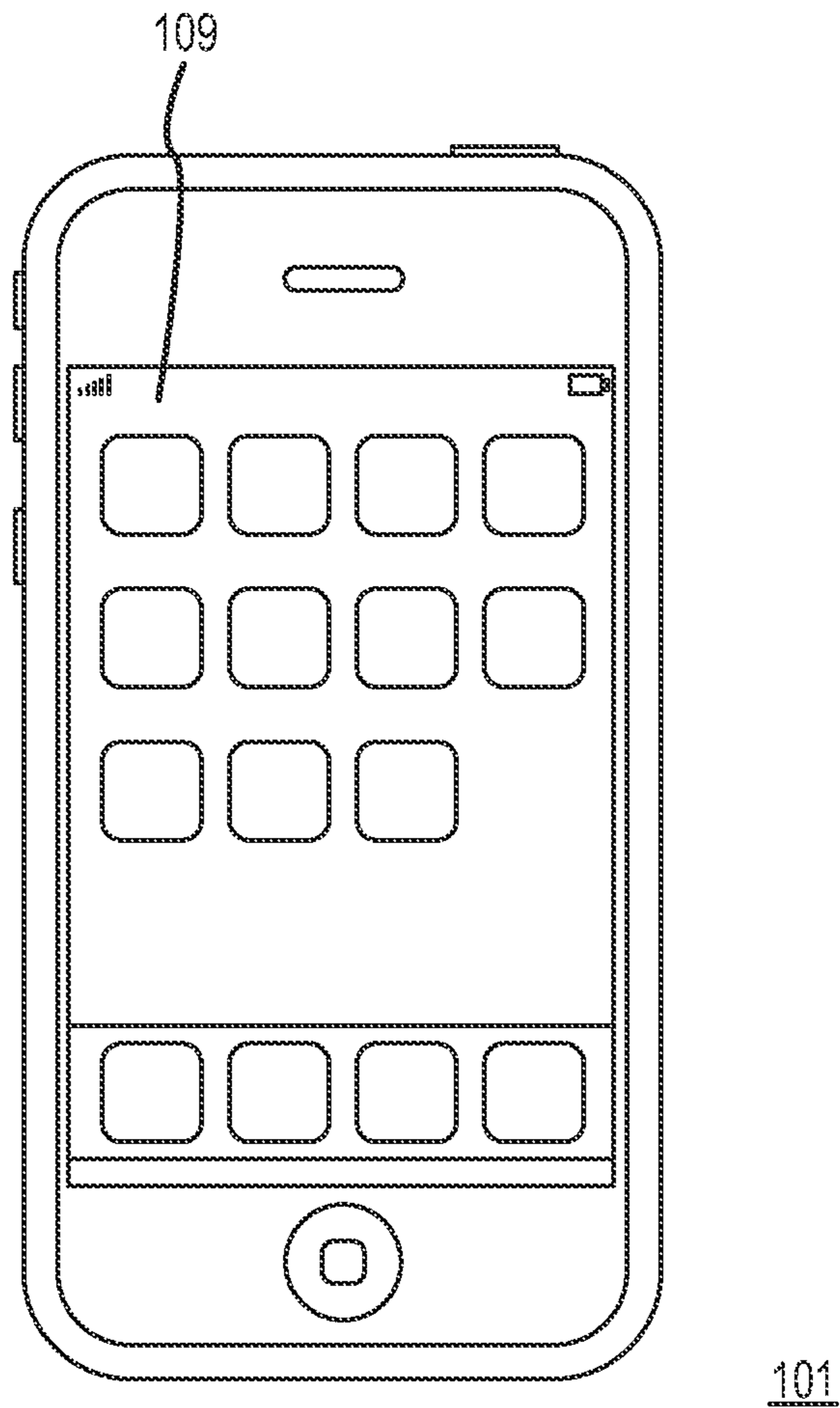
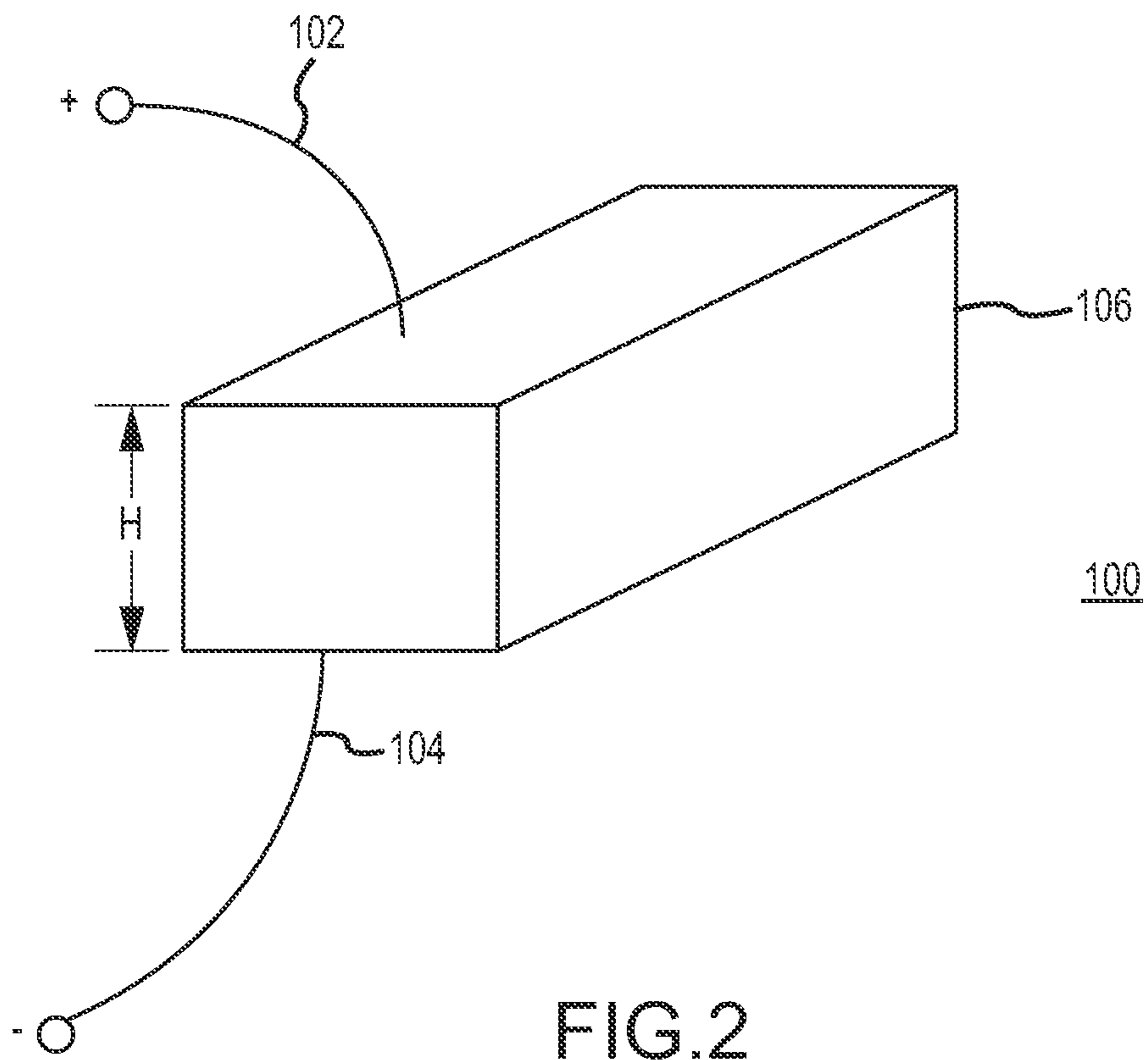
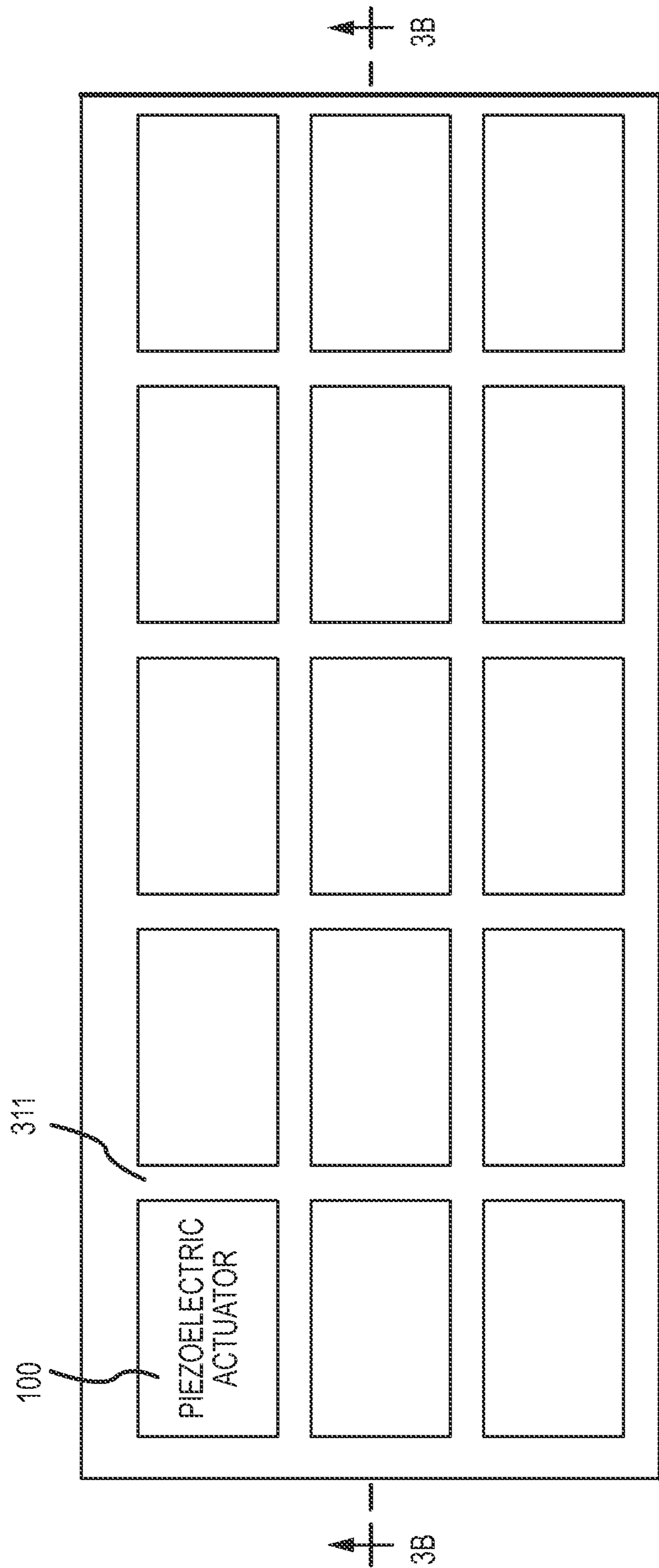


FIG. 1C







300

FIG. 3A

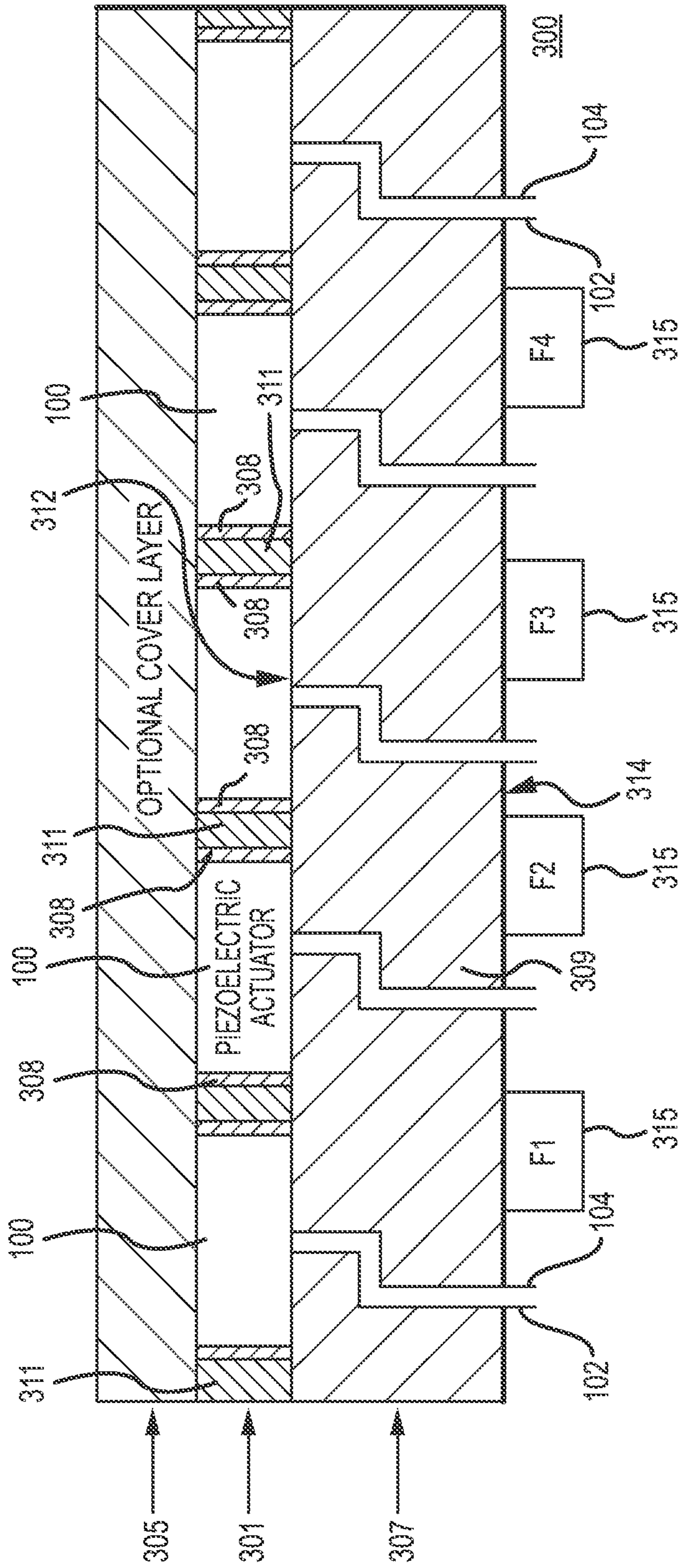


FIG. 3B

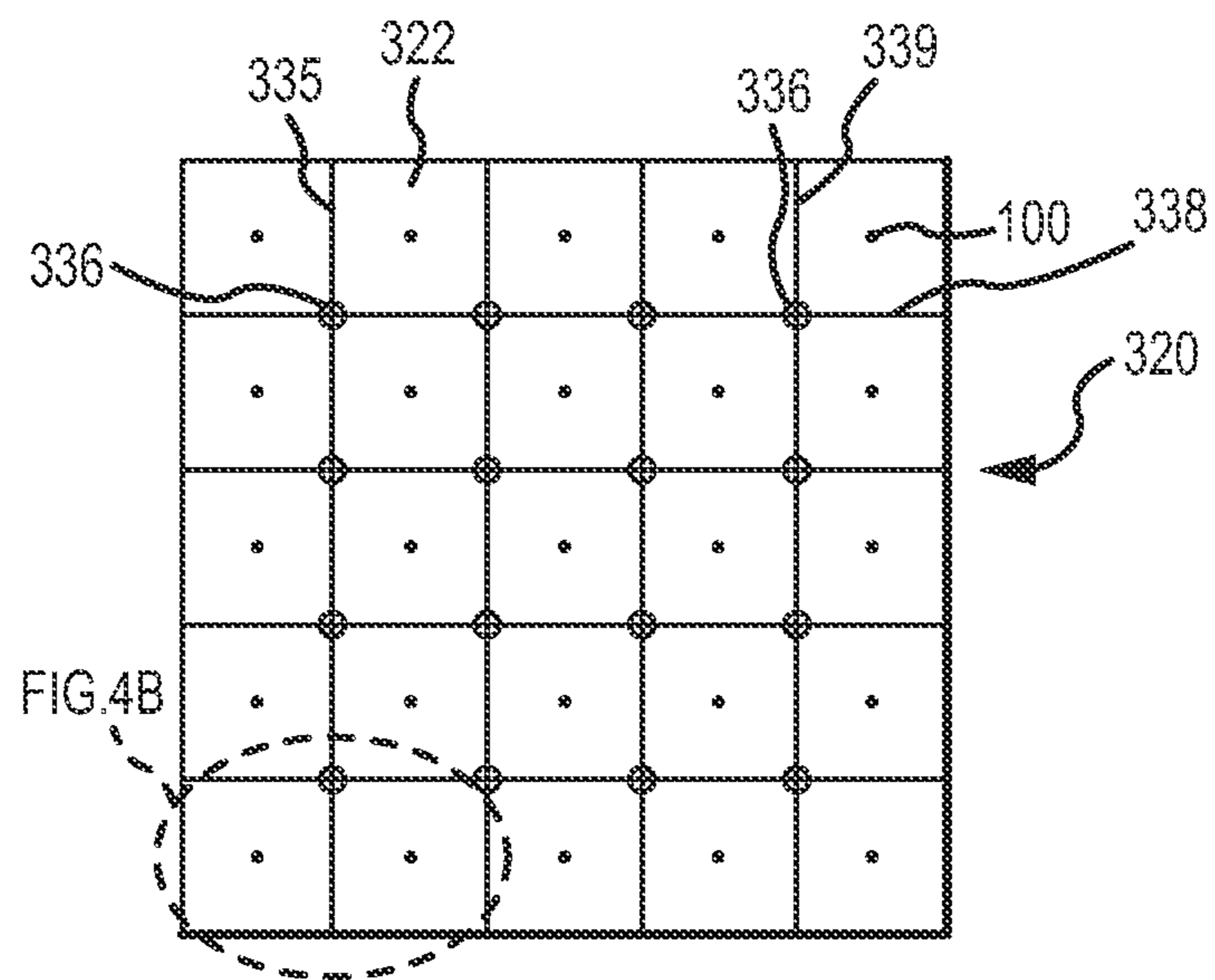


FIG.4A

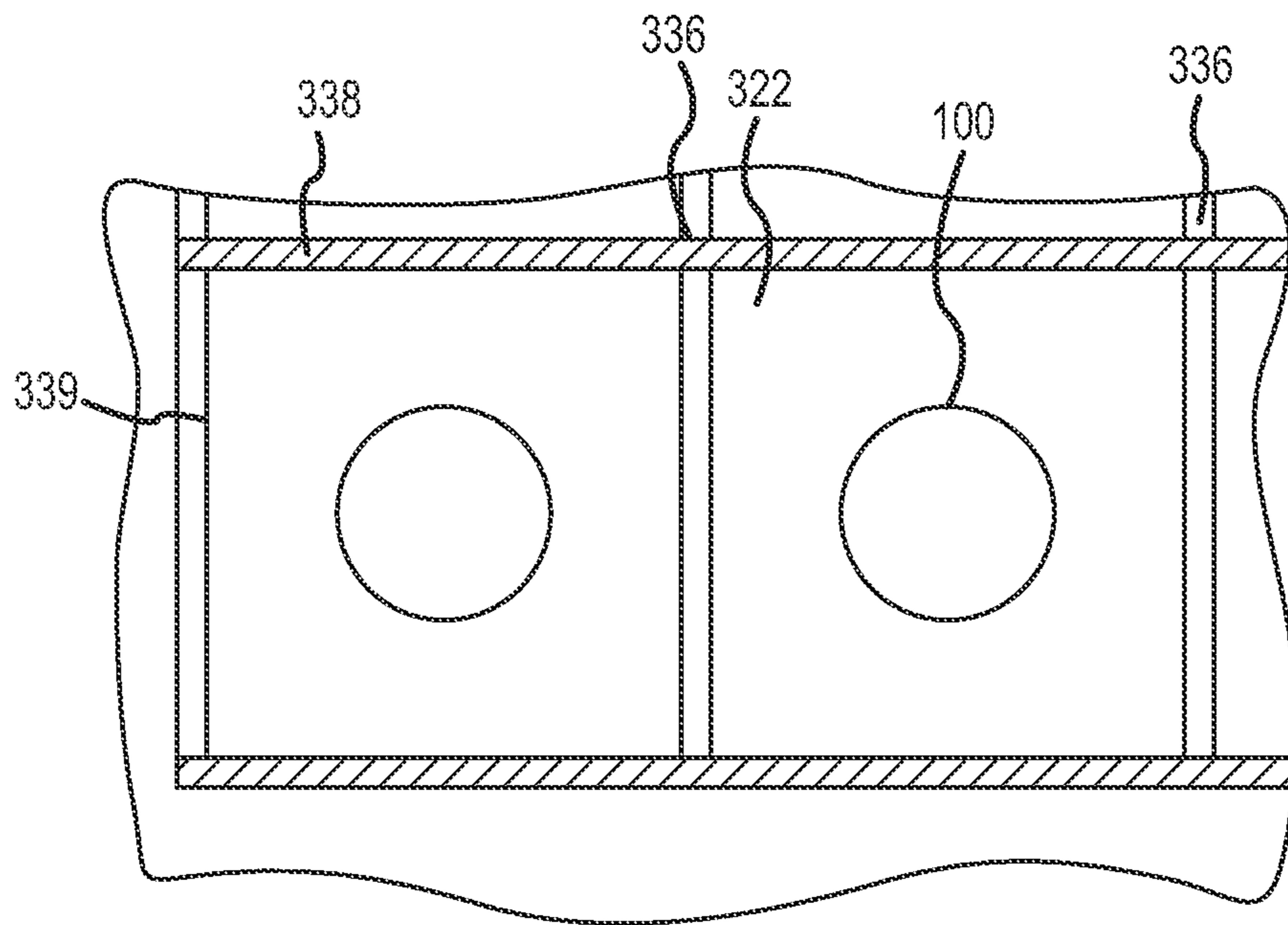


FIG. 4B

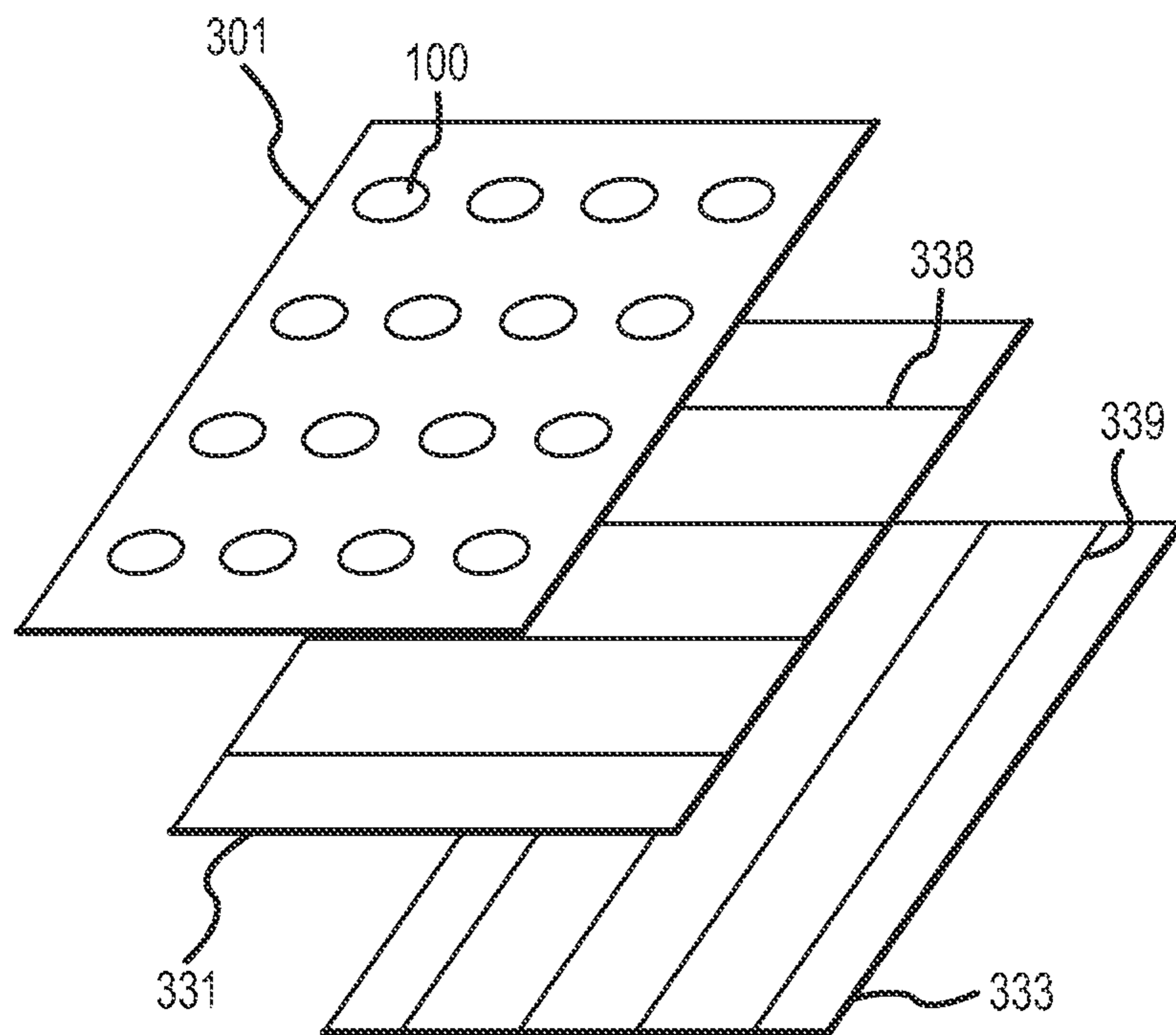
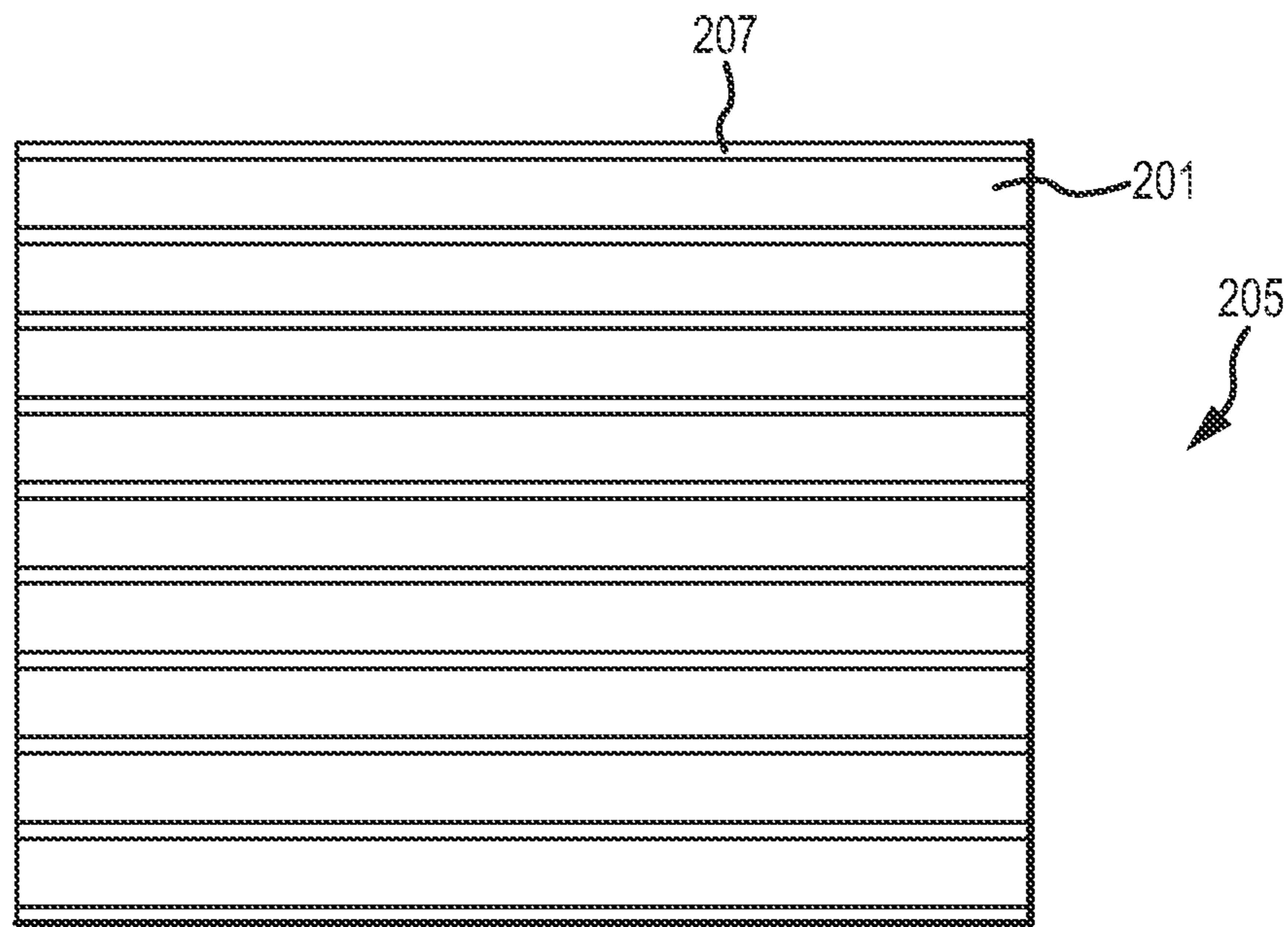


FIG. 4C



200

FIG.5A

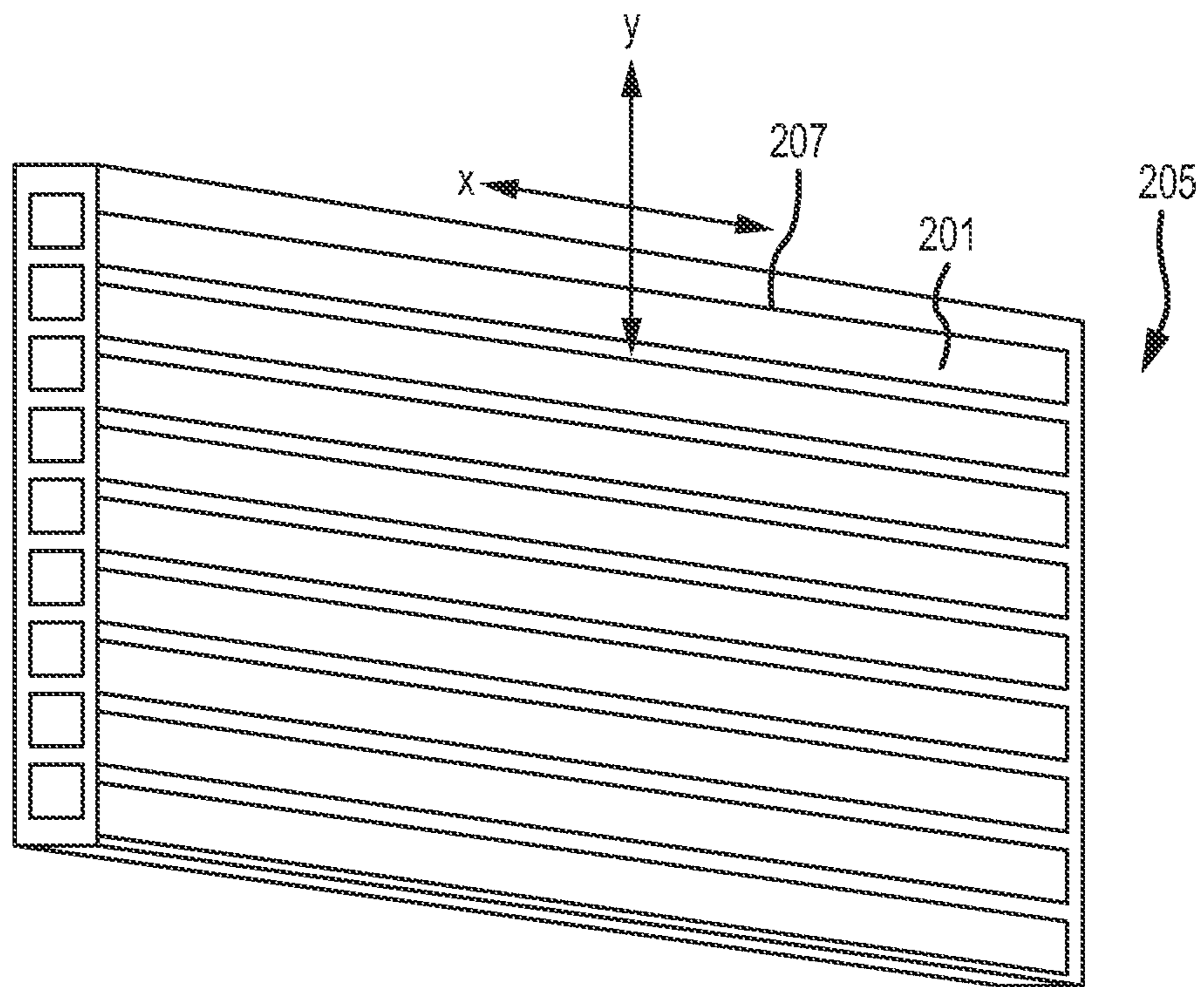


FIG. 5B



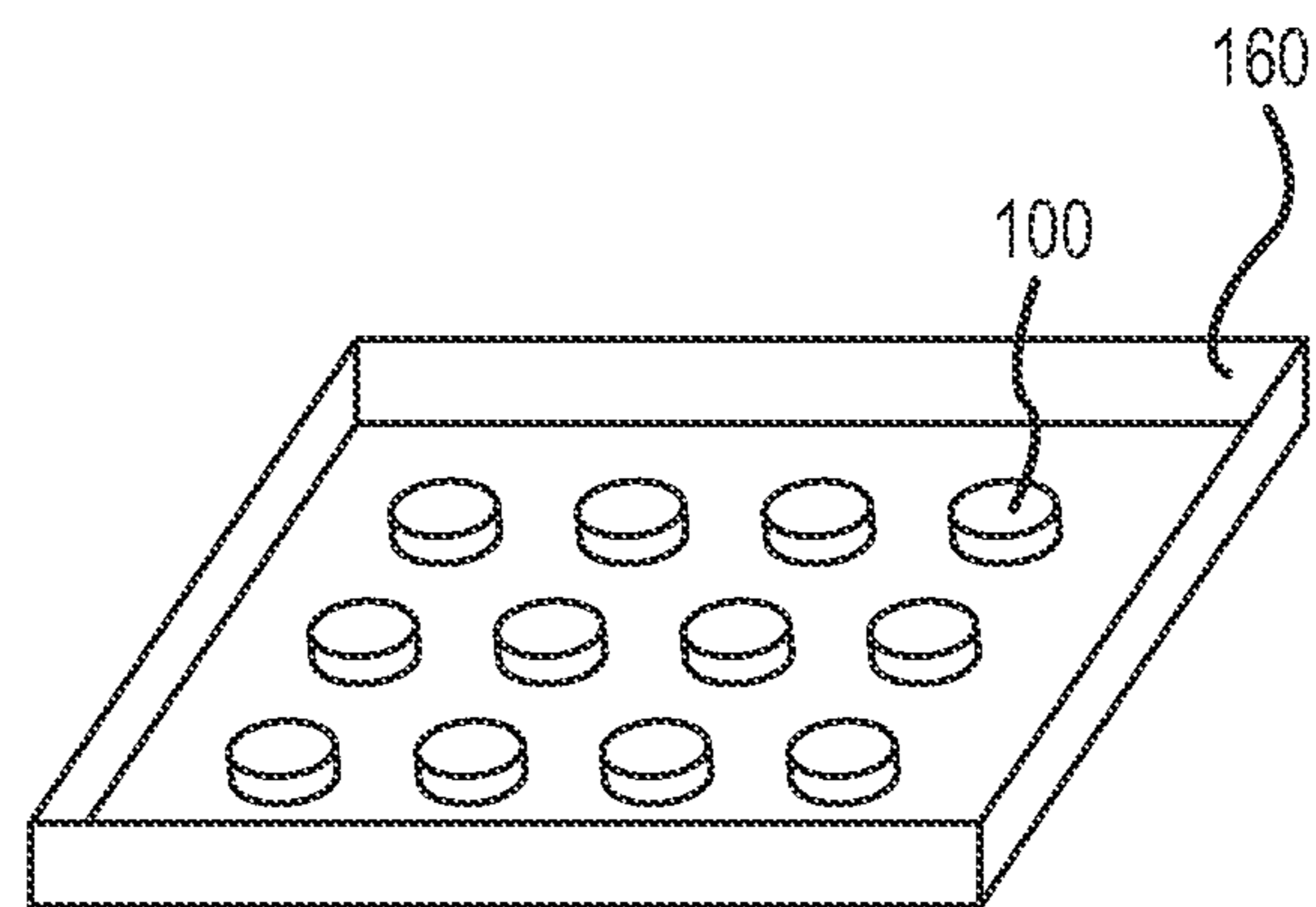


FIG.6A

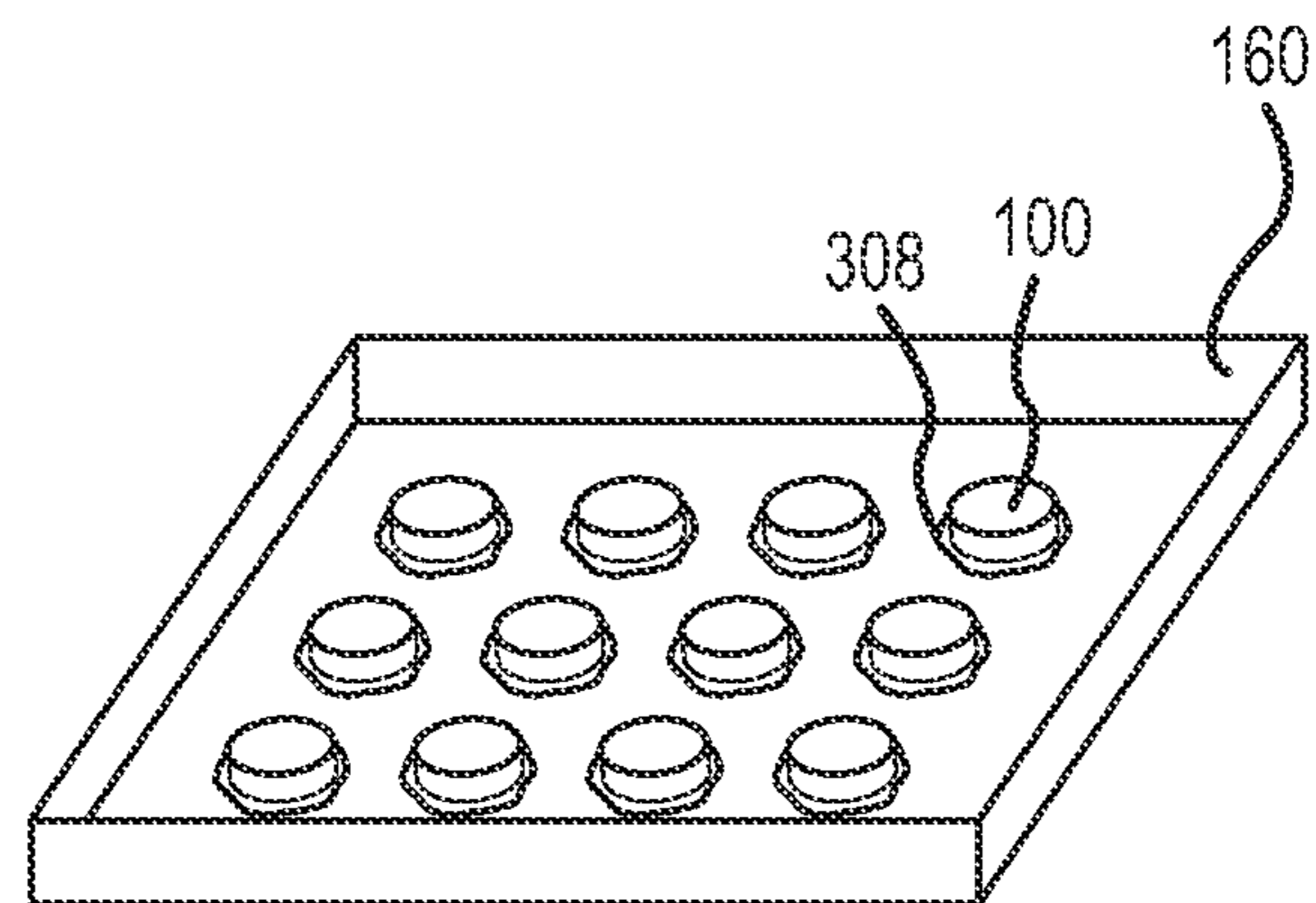


FIG. 6B

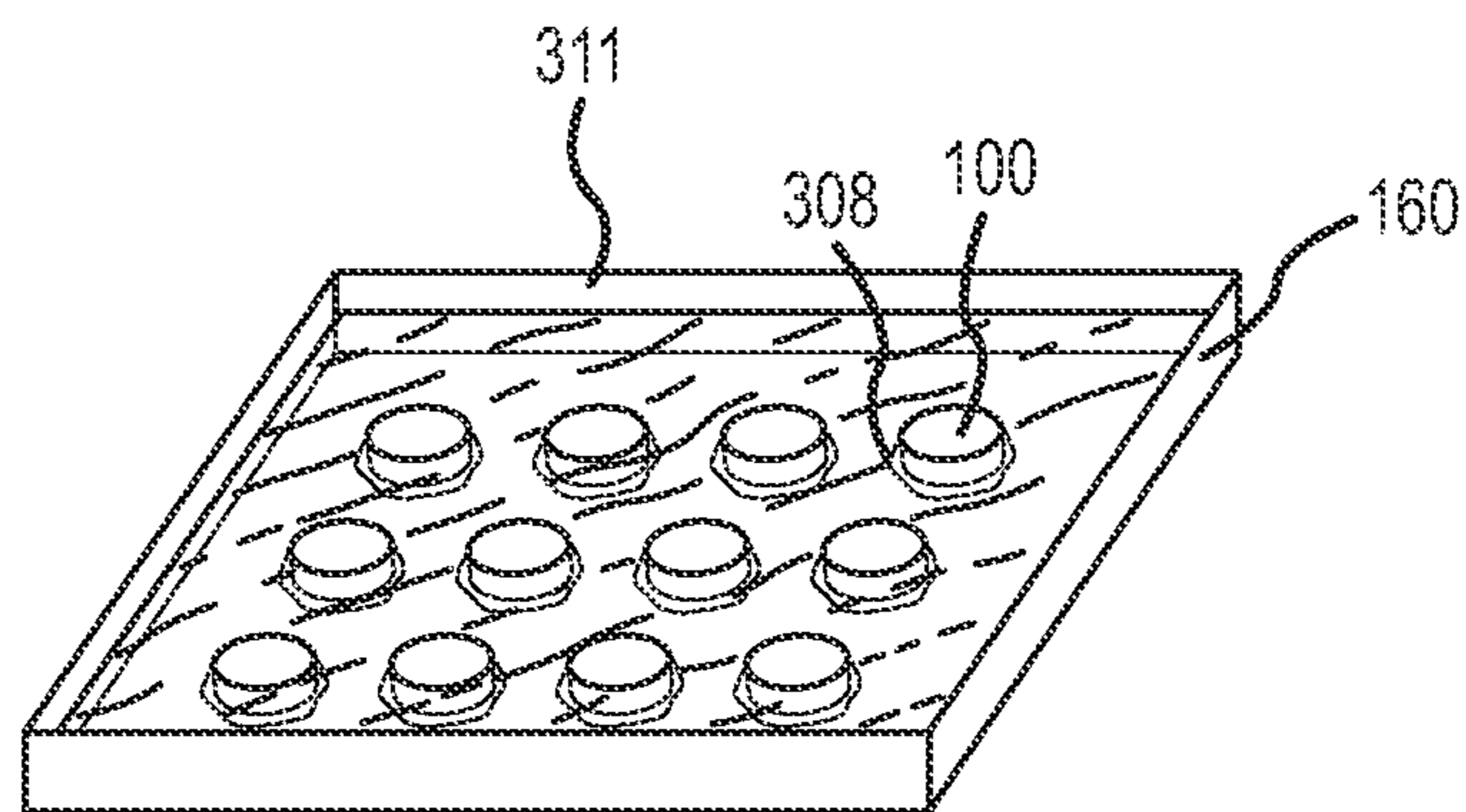


FIG. 6C

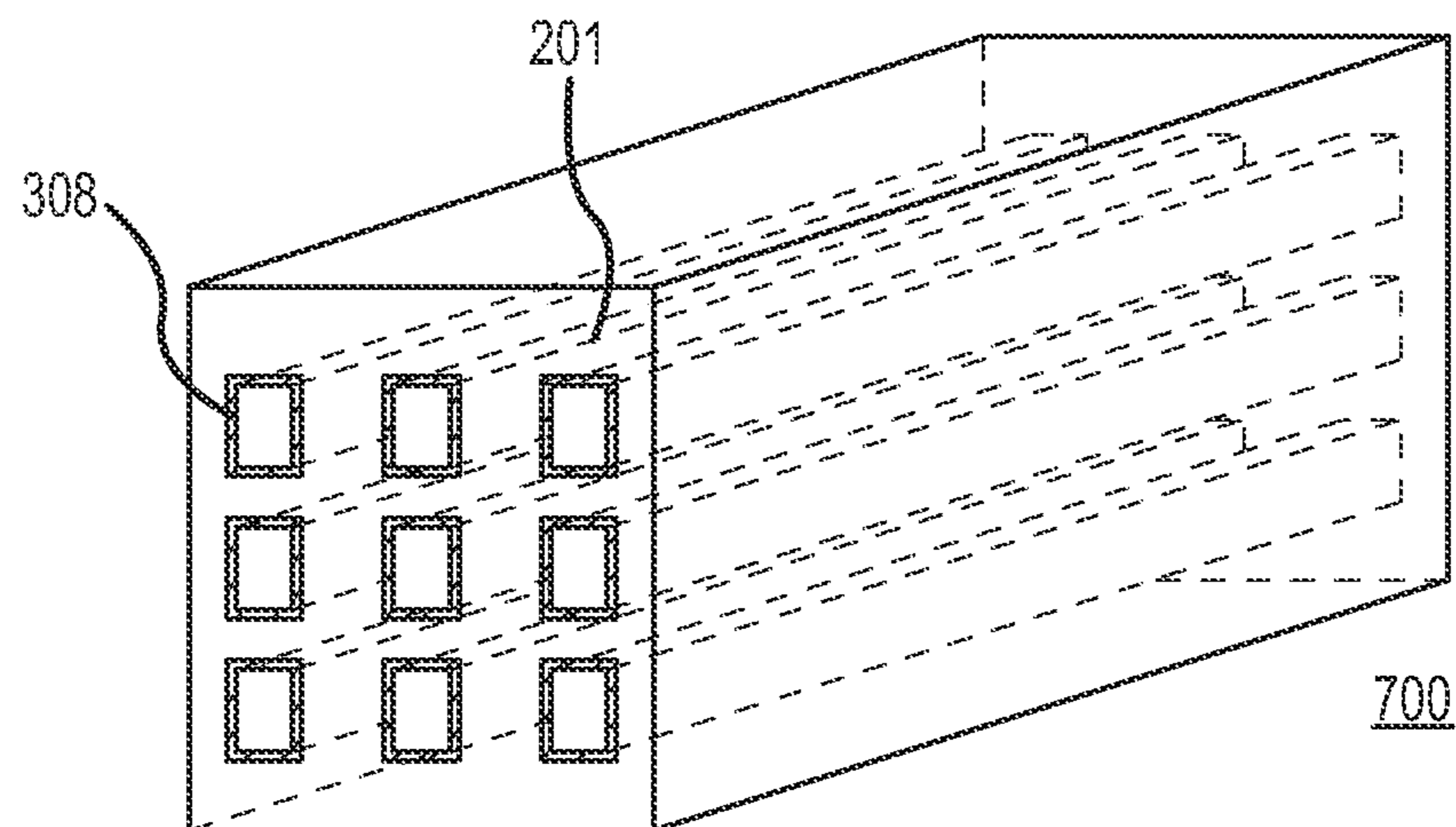


FIG.7A

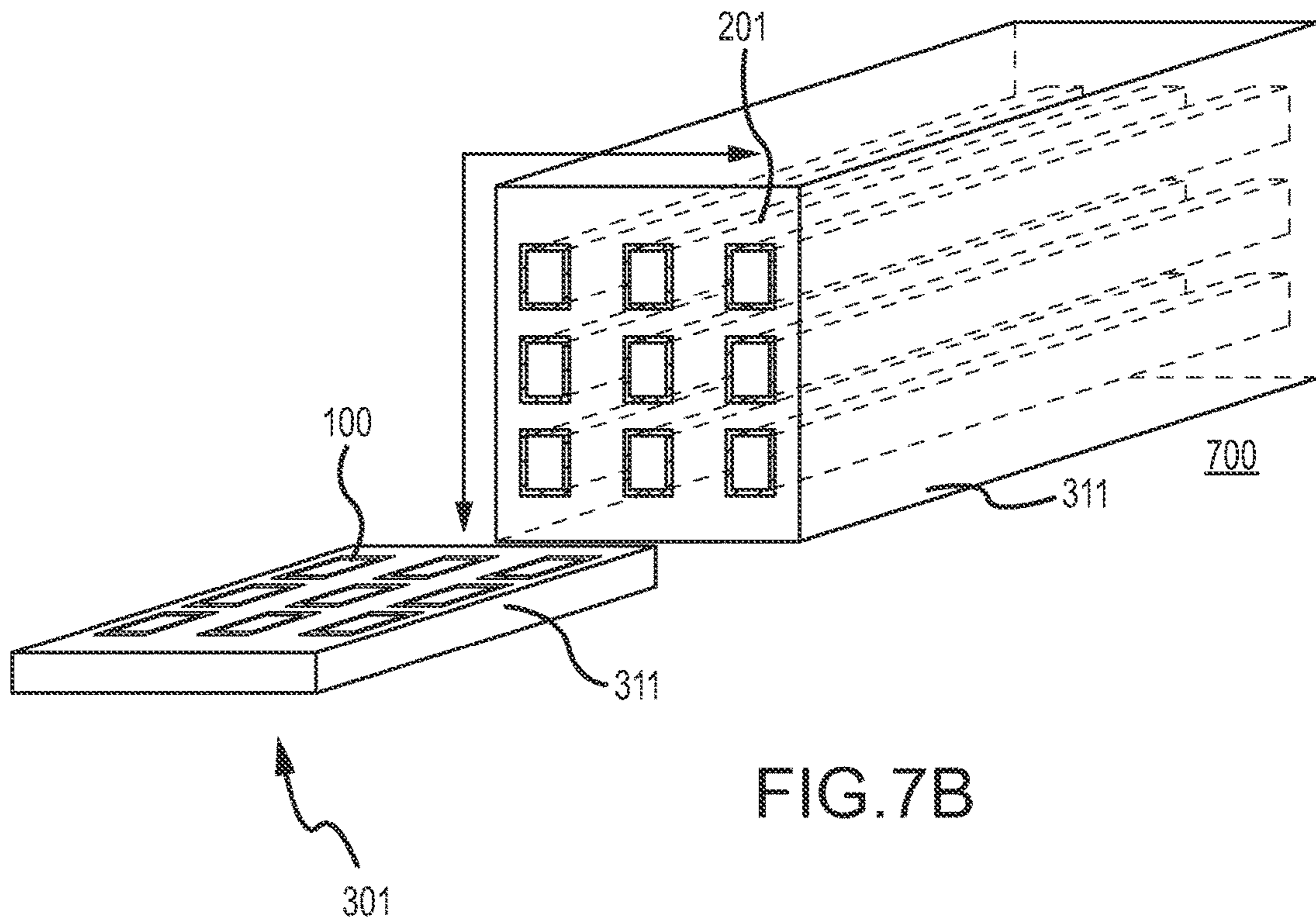


FIG. 7B

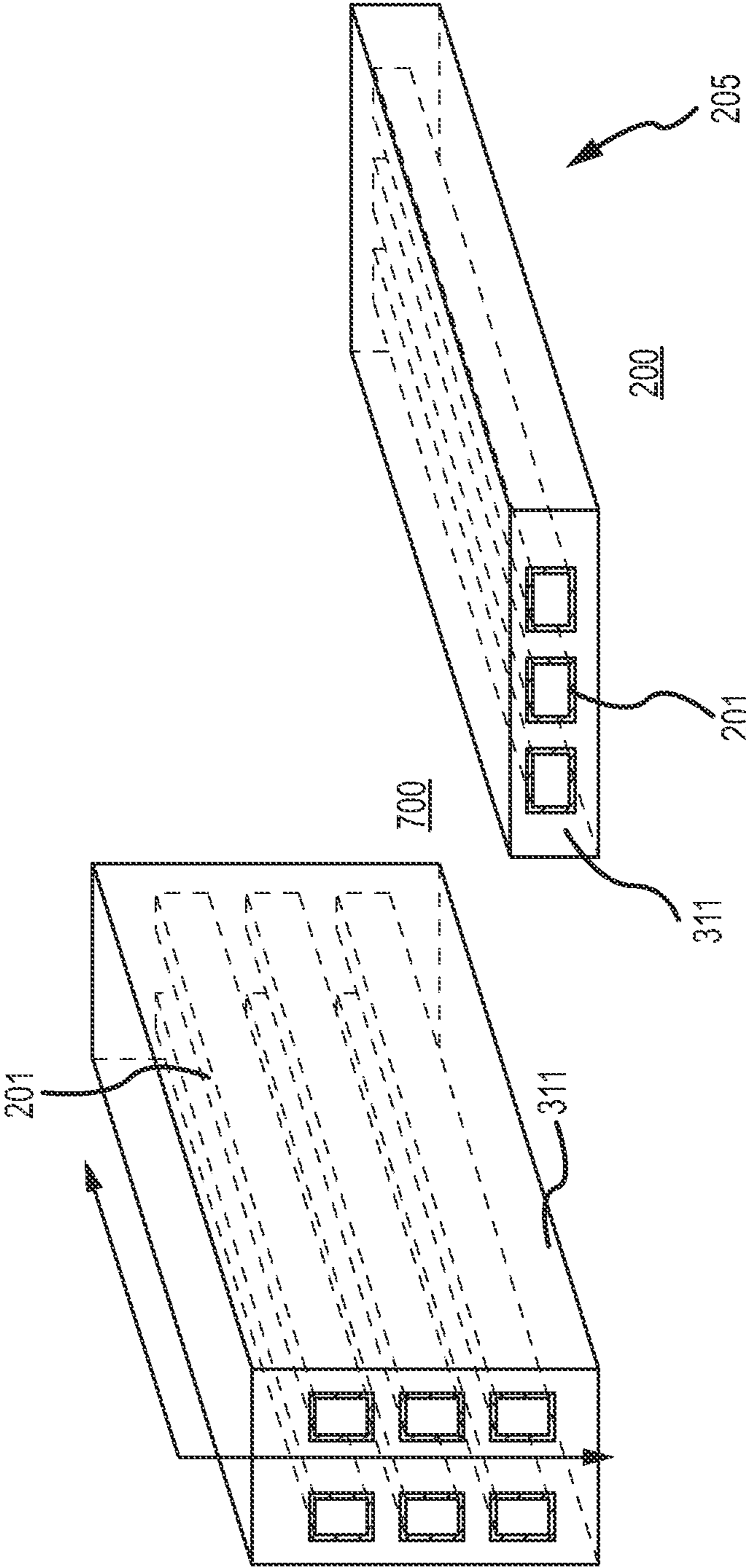


FIG.7C

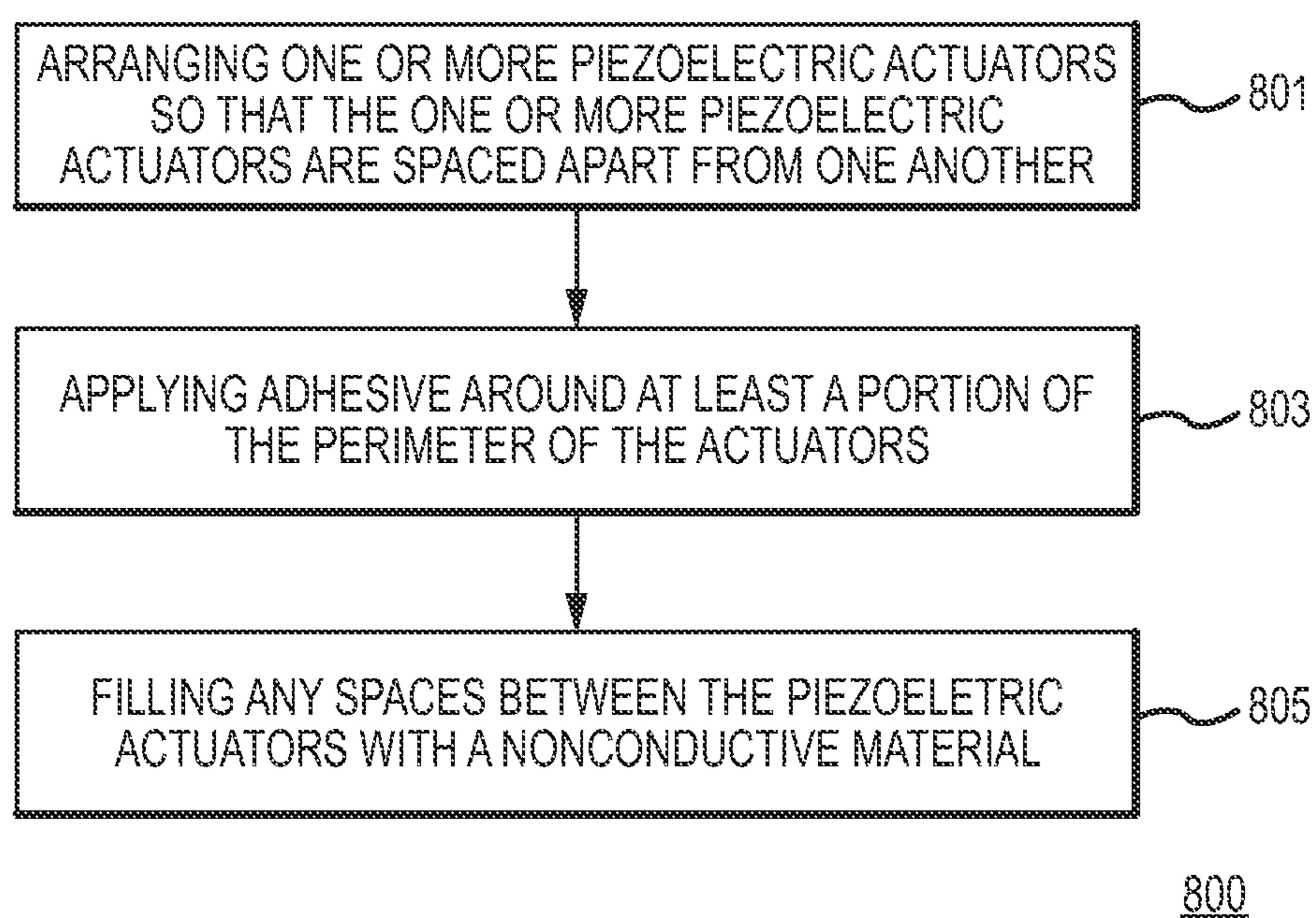


FIG. 8

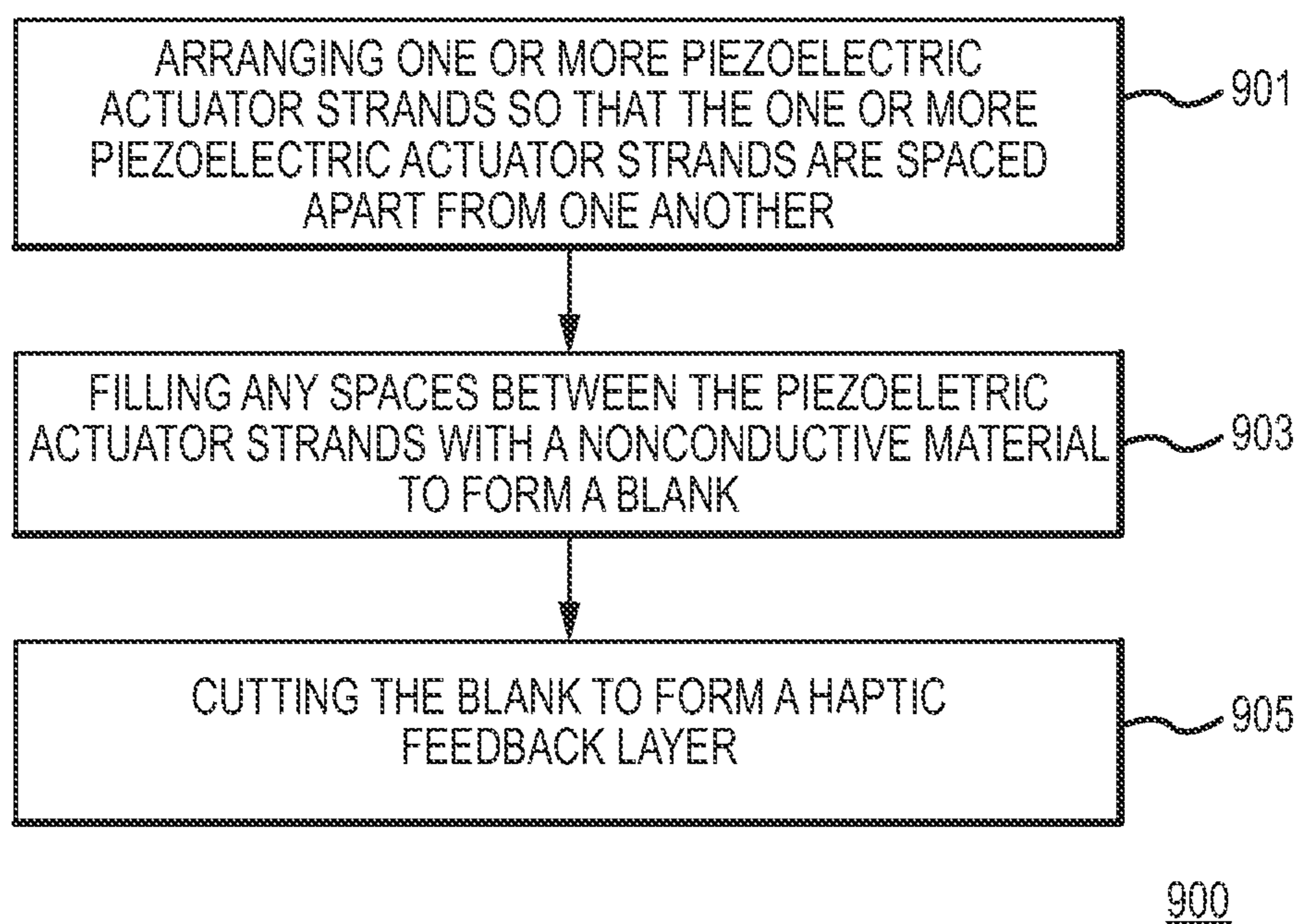


FIG.9



## TOUCH-BASED USER INTERFACE WITH HAPTIC FEEDBACK

### BACKGROUND

#### I. Technical Field

Embodiments described herein relate generally to touch-based user interfaces, such as a track pad or a touch screen, and more particularly, to touch-based user interfaces capable of providing localized haptic feedback to a user.

#### II. Background Discussion

Existing touch-based user interfaces typically have a touch panel and a visual display component. The touch panel may include a touch sensitive surface that, in response to detecting a touch event, generates a signal that can be processed and utilized by other components of an electronic device. The touch sensitive surface may be separate from the display component, such as in the case of a trackpad, or may be integrated into or positioned in front of the viewable area of the display screen, such as in the case of a display touchscreen.

In either case, the display component may display textual and/or graphical display elements representing selectable virtual buttons or icons, and the touch sensitive surface may allow a user to navigate the content displayed on the display screen. Typically, a user may move one or more objects, such as a finger or a stylus, across the touch sensitive surface in a pattern that the device translates into an input command. As an example, some electronic devices allow the user to select a virtual button by tapping a portion of the touch sensitive surface corresponding to the virtual button. Other electronic devices include a touch sensitive surface that can detect more than one simultaneous touch events in different locations on the touchscreen.

Existing touch-based user interfaces do not provide haptic feedback to a user. Haptic feedback may be any type of tactile feedback that takes advantage of a user's sense of touch, for example, by applying forces, vibrations, and/or motions to the user. The user can typically only feel the rigid surface of the touch screen, making it difficult to find icons, hyperlinks, textboxes, or other user-selectable input elements that are being displayed. A touch-based user interface may help a user navigate content displayed on the display screen by incorporating haptic feedback. For example, localized haptic feedback can enable a user to feel what is being displayed by providing feedback when a user locates a virtual button, selects the virtual button and/or confirms the selection of the virtual button.

### SUMMARY

Embodiments described herein relate to touch-based user interface devices that can both receive an input from a user and provide haptic feedback based on the input from the user. In one embodiment, a touch-based user interface device may include a haptic feedback layer that includes one or more piezoelectric actuators that are embedded in a nonconductive material. The haptic feedback layer may be the outermost layer of the touch-based user interface device so that the mechanical stimulation provided by the actuators can be felt by a user. However, in other embodiments, the haptic feedback layer may be covered by a protective coating or cover layer. In some embodiments, a printed circuit board layer may be positioned underneath the haptic feedback layer. The printed circuit board layer may include one or more metallic traces that are configured to supply a voltage to each of the piezoelectric actuators embedded in

the haptic feedback layer. Some embodiments may also include input sensors, such as a displacement sensor and/or force sensor for recognizing and distinguishing between various touch-based input gestures from a user.

One embodiment may take the form of a touch-based user interface that includes a haptic feedback layer including one or more actuators configured to supply a haptic feedback. The one or more actuators may be embedded in a nonconductive material. The touch-based user interface may further include a printed circuit board layer underlying the haptic feedback layer. The printed circuit board layer may include one or more conductive traces configured to supply a voltage to the one or more actuators.

Another embodiment may take the form of a method for manufacturing a haptic feedback layer. The method may include arranging one or more piezoelectric actuators so that the one or more piezoelectric actuators are spaced apart from one another, and filling any spaces between the piezoelectric actuators with a nonconductive material.

Another embodiment may take the form of a method for manufacturing a haptic feedback layer. The method may include arranging one or more piezoelectric actuator strands so that the one or more piezoelectric actuator strands are spaced apart from one another, filling any spaces between the piezoelectric actuator strands with a nonconductive material to form a blank, and cutting the blank to form a haptic feedback layer.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A illustrates one embodiment of an electronic device that incorporates an embodiment of a touch-based user interface.

FIG. 1B illustrates another embodiment of an electronic device that incorporates an embodiment of a touch-based user interface.

FIG. 1C illustrates another embodiment of an electronic device that incorporates an embodiment of a touch-based user interface.

FIG. 2 illustrates a perspective view of a single piezoelectric actuator, as used in accordance with some embodiments.

FIG. 3A illustrates a top down view of one embodiment of a touch-based user interface.

FIG. 3B illustrates a side cross-sectional view of the touch-based user interface shown in FIG. 3A, as taken along line 3B-3B.

FIG. 4A illustrates a top down view of one embodiment of a displacement sensor overlaying one or more piezoelectric actuators.

FIG. 4B illustrates a close up and partially cut-away view of the embodiment shown in FIG. 4A.

FIG. 4C illustrates an exploded view of the embodiment shown in FIG. 4A.

FIG. 5A illustrates a top down view of another embodiment of a touch-based user interface.

FIG. 5B illustrates a perspective view of the embodiment of the touch-based user interface shown in FIG. 5A.

FIG. 6A illustrates a perspective view of a sample embodiment shown in FIGS. 3A and 3B, shown during manufacturing of the embodiment before an adhesive is applied around the edges of the piezoelectric actuators.

FIG. 6B illustrates a perspective view of the sample embodiment of FIGS. 3A and 3B, shown during manufacturing of the embodiment before nonconductive material is added to the mold.

FIG. 6C illustrates a perspective view of the sample embodiment of FIGS. 3A and 3B, shown during manufacturing of the embodiment after the spaces between the piezoelectric actuators have been filled with nonconductive material.

FIG. 7A illustrates a perspective view of the sample embodiments shown in FIGS. 3A and 3B and FIGS. 5A and 5B, shown during manufacturing of these embodiments from a composite blank before the composite blank is cut.

FIG. 7B illustrates a perspective view of a sample embodiment shown in FIGS. 3A and 3B, shown during manufacturing of the embodiment after the composite blank is cut.

FIG. 7C illustrates a perspective view of a sample embodiment shown in FIGS. 5A and 5B, shown during manufacturing of the embodiment after the composite blank is cut.

FIG. 8 is a flowchart setting forth a method for manufacturing a haptic feedback layer.

FIG. 9 is a flowchart setting forth a method for manufacturing a haptic feedback layer.

#### DETAILED DESCRIPTION

Embodiments described herein relate to touch-based user interface devices that can both receive an input from a user and provide haptic feedback based on the input from the user. In one embodiment, a touch-based user interface device may include a haptic feedback layer that includes one or more piezoelectric actuators that are embedded in a nonconductive material. The haptic feedback layer may be the outermost layer of the touch-based user interface device so that the mechanical stimulation provided by the actuators can be felt by a user. However, in other embodiments, the haptic feedback layer may be covered by a protective coating or cover layer. In some embodiments, a printed circuit board layer may be positioned underneath the haptic feedback layer. The printed circuit board layer may include one or more metallic traces that are configured to supply a voltage to each of the piezoelectric actuators embedded in the haptic feedback layer. Some embodiments may also include input sensors, such as displacement and/or force sensors for recognizing and distinguishing between various touch-based input gestures from a user.

The term “vertical” as used herein is defined as a plane perpendicular to the plane or surface of the haptic feedback layer, regardless of its orientation. The term “horizontal” refers to a direction perpendicular to the vertical direction just defined. Terms such as “above,” “below,” “bottom,” “beneath,” “top,” “side,” “higher,” “lower,” “upper,” “over,” and “under” (e.g., as in “underlying,” “underneath,” and so on) are defined with respect to the plane perpendicular to the plane or surface of the haptic feedback layer, regardless of its orientation. The term “outermost” refers to the surface positioned closest to a user engaging the surface. The term “outer,” as in “outer surface,” refers to any surface of an object, which can include the outermost surface.

FIGS. 1A-1C illustrate some examples of electronic devices that incorporate various embodiments of touch-based user interfaces. In one embodiment, shown in FIG. 1A, a laptop 111 may incorporate a trackpad 104 that serves as a user input-output (I/O) device. The trackpad 104 may be separate from the display screen 103 of the laptop 100.

As will be further described below, the trackpad 104 may include one or more input sensors that allow a user to interact with the laptop 111, as well as a surface capable of providing dynamic localized haptic feedback. In one

embodiment, the trackpad 104 may be configured to sense various touch-based input gestures, such as swiping, taping, scrolling, and so on, applied across the surface of the trackpad 104. The touch-based input gestures may be applied by an object, such as a finger, a stylus, and so on. The input sensors may obtain information regarding the sensed gestures and transmit the information to a processing device provided in the laptop 111, which may translate the received information to a particular input command. As an example, the input sensors may derive distance and/or direction information regarding a sensed gesture, and the processing device may move a graphical pointer on the screen based on the received distance and/or direction information. As another example, the input sensors may be configured to sense a particular motion or pattern of motions and associate the sensed motion with a particular command. For example, a tap may be associated with a mouse click, while sliding the object along the trackpad in a particular manner may be associated with scrolling. The processing device may be any known processing device, including, but not limited to, a central processing unit (CPU), a microprocessor, a digital signal processor (DSP), a microcontroller, a graphics processing unit (GPU), and so on.

As discussed above, the trackpad 104 may be configured to provide haptic feedback based on the input gestures from the user. The haptic feedback may be used to enhance the user’s interaction with the laptop 111 by providing mechanical stimulation to the user when the user is engaging the trackpad 104. For example, the haptic feedback may confirm the user’s selection of a particular virtual icon or button, or may be provided when the user’s cursor passes a selectable icon or button. Other embodiments may include other ways of providing haptic feedback to the user. The haptic feedback may be provided by one or more actuators configured to apply forces, vibration, and/or other motions to the object engaging the trackpad 104. As will be further discussed below, in one embodiment, the actuators may be distributed throughout the surface of the trackpad 104 so that a user may receive the feedback from different portions of the trackpad 104. In other embodiments, the actuators may only be provided in certain sections of the surface of the trackpad 104, so that the user may only receive feedback when engaging those sections. As will be discussed below, the actuators may be piezoelectric actuators.

FIG. 1B illustrates another embodiment, in which the touch-based user interface may be incorporated into the housing of a mouse 108. One example of an existing mouse 108 incorporating such a touch-based user interface is Apple Inc.’s Magic Mouse™. The mouse 108 may include one or more sensors for detecting various touch-based input gestures, such as swiping, taping, single and two-finger scrolling, and so on, across the top surface 107 of the mouse 108 for allowing a user to interact with a desktop computer 105. In one embodiment, the top surface 107 of the mouse 108 may include a number of actuators that may provide haptic feedback to the user based on the user’s interactions with the desktop computer 105. Like the trackpad 104 of the embodiment shown in FIG. 1A, the mouse 108 may be separate from the display screen 102 of the desktop computer 105.

In yet another embodiment, illustrated in FIG. 1C, the touch-based user interface may take the form of a touchscreen input component 106. The touchscreen input component 106 may be provided on an electronic device 101 that can function as, for example, a media device, a communications device, a digital camera, a video camera, a storage device, or any other electronic device. Some examples of electronic devices 101 incorporating touch-based user inter-

5

faces include Apple Inc.'s iPhone™ and iPad™. The electronic device **101** may include one or more sensors for detecting various touch-based input gestures, such as swiping, tapping, scrolling, and so on, across a surface **109** overlaying the display screen of the electronic device **101** for allowing a user to interact with the device. In some embodiments, the surface **109** may include a number of actuators that may provide haptic feedback in response to the input gestures from the user.

FIG. 2 shows a perspective view of a single piezoelectric actuator **100**, as used in accordance with some embodiments. As discussed above, the piezoelectric actuator **100** may provide some type of mechanical stimulation, such as a pulse, vibration, or other feedback, upon actuation. The surface area of actuator **100** can be, for example, 10 square millimeters, 10 square micrometers, 10 square nanometers, or any other size that is physically possible. Additionally, while the illustrated piezoelectric actuator **100** has a rectangular configuration, other embodiments may be other shapes. For example, the piezoelectric actuator may be circular, ovalar, triangular, elongated strands, and so on and so forth.

The piezoelectric actuator **100** may include electrodes **102** and **104** and piezoelectric material **106**, any or all of which can be transparent, opaque, or a combination thereof. The piezoelectric material **106** can include, for example, a ceramic, polyvinylidene fluoride, one or more natural crystals (such as, e.g., Berlinite, cane sugar, quartz, Rochelle salt, topaz, and/or any tourmaline group mineral(s)), man-made crystals (such as, e.g., Gallium orthophosphate or langasite), bone, polymers, and/or any other material that is able to mechanically deform in response to an applied voltage.

The piezoelectric material **106** may be connected to two electrodes **102** and **104**. One of the electrodes **102** may be connected to a positive terminal of a voltage source and the other of the electrodes **104** may be connected to a negative terminal of a voltage source. When a sufficient voltage is applied across the electrodes **102** and/or **104**, the piezoelectric material **106** can expand or contract in height (H). In other embodiments, the piezoelectric actuator **100** can be made to expand in other directions, such as in width, as opposed to height. The amount of voltage required to deform the piezoelectric material **106** may vary, and may depend on the type of piezoelectric material **106** used to manufacture the piezoelectric actuator **100**. When no voltage is supplied by the voltage source, or when the voltage across the electrodes **102**, **104** is less than the threshold amount of voltage required to deform the piezoelectric material **106**, the piezoelectric material **106** may return to its original dimensions (i.e., the dimensions of the material in its undeformed state).

The magnitude of expansion or contraction of the piezoelectric material **106** may be determined by the level or amount of voltage across the electrodes **102**, **104**, with a larger amount of voltage corresponding to a higher magnitude of expansion or contraction. Additionally, the polarity of the voltage across the piezoelectric material **106** may determine whether the piezoelectric material **106** contracts or expands. For example, the piezoelectric material **106** may expand in response to a positive voltage and contract in response to a negative voltage. Alternatively, the piezoelectric material may contract in response to a positive voltage and expand in response to a negative voltage.

In one embodiment, the piezoelectric actuator **100** can be made to vibrate by applying a control signal to one or both of the electrodes **102** and **104** of the piezoelectric actuator

6

**100**. The control signal may be a wave having a predetermined amplitude and/or frequency. When the control signal is applied to one or both of the electrodes **102**, **104**, the piezoelectric actuator **100** may vibrate at the frequency of the control signal. The frequency of the control signal may be adjusted according to various embodiments to alter the rate of expansion and contraction of the piezoelectric actuators **100** if a more or less rapid vibration is desired. The amplitude of the control signal may be correlated to the magnitude of expansion or contraction of the piezoelectric material **106**, and may be adjusted to alter the intensity of the vibration.

FIG. 3A illustrates a top down view of one embodiment of a touch-based user interface **300**. A cross-sectional view of the touch-based user interface **300** shown in FIG. 3A is illustrated in FIG. 3B. As shown in FIGS. 3A and 3B, the touch-based user interface **300** may include an optional cover layer **305**, a haptic feedback layer **301**, a printed circuit board ("PCB") layer **307**, and one or more force sensors **315**. In one embodiment, the optional cover layer **305** may be positioned above the haptic feedback layer **301**, the PCB layer **307** may be positioned below the haptic feedback layer **301**, and the force sensors **315** may be positioned below the PCB layer **307**. Other embodiments may include other arrangements of the haptic feedback layer **301**, the PCB layer **307**, force sensors **315** and cover layer **305**. For example, in one embodiment, the haptic feedback layer **301** may be positioned underneath the PCB layer **307**. Another embodiment may not include a cover layer **305**. Instead, the haptic feedback layer **301** may form the outermost surface of the touch-based user interface **300**. In a further embodiment, the force sensors **315** may be positioned above the haptic feedback layer **301**.

In one embodiment, the haptic feedback layer **301** may include one or more piezoelectric actuators **100** embedded in a nonconductive material **311**. Each of the piezoelectric actuators **100** in the haptic feedback layer **301** may be the same as or similar to the piezoelectric actuator **100** shown and described in FIG. 2. In one embodiment, each piezoelectric actuator **100** may be individually controlled. In other embodiments, two or more piezoelectric actuators **100** can be grouped together and controlled as a single entity. For example, two or more piezoelectric actuators can be grouped together to represent a single virtual button. In further embodiments, any number of piezoelectric actuators **100** can be grouped to form a single entity.

One skilled in the art will appreciate that, despite the actuators shown in FIGS. 3A and 3B having the same physical dimensions, the piezoelectric actuators can be any size, or combination of sizes. For example, the piezoelectric actuators can be larger around the edges of the touch-based user interface **300** and proportionately smaller towards the middle of the touch-based user interface **300**. One skilled in the art would also appreciate that the space between piezoelectric actuators and/or the piezoelectric actuators' piezoelectric material can also be adjusted accordingly.

As shown in FIGS. 3A and 3B, the piezoelectric actuators **100** may be embedded into the haptic feedback layer **301** in any configuration. For example, as shown in FIG. 3A, the piezoelectric actuators **100** may be arranged in a grid configuration to form a plurality of rows and columns. The number of rows and columns of piezoelectric actuators **100** on the touch-based user interface **300** may vary according to different embodiments. For example, one embodiment may include more rows than columns, while another embodiment may include equal numbers of rows and columns, and so on and so forth.

The piezoelectric actuators **100** may be embedded in a nonconductive material **311** that may serve to insulate the actuators **100** and separate the actuators **100** from one another. The nonconductive material **311** may be an inorganic or rigid material that has a sufficiently high modulus of rigidity to resist deformation when the embedded piezoelectric actuators **100** deform in response to a supplied voltage. In this embodiment, the nonconductive material **311** may maintain the same dimensions as the attached actuators **100** increase and decrease in height relative to the nonconductive material **311**. Some examples of inorganic materials that may be used include glass, ceramic, plastic, and so on and so forth. In other embodiments, the nonconductive material **311** may be an organic or compliant material that has a sufficiently high modulus of elasticity to deform with the attached embedded piezoelectric actuators **100**. In this embodiment, the nonconductive material **311** may increase and decrease in height as the attached embedded actuators **100** increase and decrease in height. Some examples of organic materials that may be used include elastomers, silicon, thermoplastics, and so on and so forth.

In one embodiment, the piezoelectric actuators **100** may be bonded to the nonconductive material **311** by an adhesive **308**. For example, the adhesive **308** may be applied around at least a portion of the perimeter of the piezoelectric actuators **100** to bond the actuators to the nonconductive material **311**. In some embodiments, the adhesive **308** may have a high modulus of elasticity so as to allow the piezoelectric actuators **100** to move relative to the nonconductive material **311** while resisting debonding of the actuators **100** and the nonconductive material, as well as cracking or wear of the adhesive itself. Some examples of suitable adhesives include, but are not limited to, a thermoplastic adhesive, a hot melt adhesive, a solvent-based adhesive, and so on and so forth.

The properties of the adhesive **308** may vary according to the properties of the nonconductive material **311** used to form the haptic feedback layer **301**. For example, an adhesive having a higher modulus of elasticity may be more suitable for embodiments utilizing a rigid nonconductive material **311** that resists deformation as the embedded piezoelectric actuators **100** are deformed. In contrast, an adhesive having a lower modulus of elasticity may be more suitable for embodiments utilizing a compliant or elastic nonconductive material **311** that is deformed with the embedded piezoelectric actuators **100**.

As discussed above, a PCB layer **307** may be positioned underneath the haptic feedback layer **301**. The PCB layer **307** may include a nonconductive matrix **309** configured to support the electrodes **102**, **104** corresponding to each of the piezoelectric actuators **100**. As shown in FIG. 3B, in one embodiment, each pair of electrodes **102**, **104** may be positioned directly beneath a corresponding piezoelectric actuator so that each of the electrodes **102**, **104** is aligned with a corresponding actuator **100** along at least one vertical axis. However, in other embodiments, the electrodes may not be vertically aligned with a corresponding actuator **100**. For example, in one embodiment, one or both of the electrodes **102**, **104** may be positioned to one side of a corresponding actuator **100**.

In one embodiment, the electrodes **102**, **104** may take the form of conductive metallic traces that are embedded within the nonconductive matrix **309**. As shown in FIG. 3B, the top ends of the metallic traces may contact the piezoelectric actuators **100**, and the metallic traces may extend from a top surface **312** of the PCB layer **307** through a bottom surface **314** of the PCB layer. The metallic traces may be formed

from any suitable electrically conductive material, including, but not limited to, copper, aluminum, silver, gold, iron, and so on and so forth. In other embodiments, the electrodes **102**, **104** may be insulated wires, rather than uninsulated traces.

The nonconductive matrix **309** may be formed from any non-conductive material, including an low-temperature co-fired ceramic, an elastomer-based polymer, glass, Teflon, and so on and so forth. In one embodiment, the nonconductive matrix **309** may be formed from a rigid or semi-rigid material that may provide structural support to the haptic feedback layer **301**. For example, the nonconductive matrix **309** may prevent the haptic feedback layer **301** from cracking when depressed. The nonconductive matrix **309** may completely surround each of the electrodes **102**, **104** so as to insulate the individual electrodes and prevent contact between adjacent electrodes. However, in other embodiments, such as where insulated wires are used rather than uninsulated traces, the nonconductive matrix **309** may only partially surround each of the electrodes **102**, **104**.

In some embodiments, the haptic feedback layer **301** may be fully or partially covered by an optional cover layer **305**. The optional cover layer **305** may serve to insulate and protect the haptic feedback layer **301** from wear. The cover layer **305** may be sufficiently thin so as to allow a user to feel the forces supplied by the actuators **100**. In one embodiment, the optional cover layer **305** may be formed from a transparent nonconductive material, such as glass, a clear cosmetic glaze, plastic, and so on. However, in other embodiments, the cover layer **305** may be formed from a fully or partially opaque material, such as a ceramic or an opaque paint. In another embodiment, the cover layer **305** may be a clear material that is sprayed or otherwise coated by an opaque paint. For example, the cover layer **305** may be a glass layer that is coated in paint.

As alluded to above, the touch-based user interface **300** may also include one or more force sensors **315**. In one embodiment, the force sensors **315** may be located beneath the PCB layer **307**. However, in other embodiments, the force sensors **315** may be positioned above the haptic feedback layer **301** or embedded into the PCB layer **307** or the haptic feedback layer **301**. The force sensors **315** may be capable of sensing the amount of force or pressure being exerted on the sensors. When a force is applied to the touch-based user interface **300**, the force may be transmitted through the outer layers of the interface to a force sensor underneath. Some examples of force sensors **315** that may be used in conjunction with the touch-based user interface may include, but are not limited to, force sensitive resistors, force sensitive capacitors, load cells, pressure plates, piezoelectric transducers, strain gauges, and so on and so forth.

In one embodiment, the force sensors **315** may be positioned underneath or incorporated into the outermost surface of the touch-based user interface **300**. In this embodiment, the outermost surface of the touch-based user interface **300** may allow for a slight amount of flex so that any forces on the surface can be distributed to a respective force sensor. Accordingly, when a force is applied to the touch-based user interface **300**, for example, due to squeezing or pushing on the outermost surface, the force may be transmitted through the outermost surface to a force sensor **315** located underneath the outermost surface. That is, the outermost surface may flex minimally, but still enough to be sensed by the force sensor **315** embedded in the outermost surface or sandwiched between the outermost surface and another intermediate layer of the touch-based user interface **300**.

The force sensors **315** may produce signals indicative of the sensed forces. In one embodiment, the sensors **315** may be configured to generate input signals when forces are applied to the touch-based user interface **300**. The processing device of the electronic device may then process the input signals to distinguish between various touch-based input gestures and initiate commands according to the different input gestures. Accordingly, the force sensors **315** may allow for distinguishing between various input gestures that may be associated with different commands. In one embodiment, the force sensors may be used to differentiate between a click and a scroll command. As an example, the processing device may associate a higher amount of force, such as from a tapping motion, with a click command and a lower amount of force, such as from a gliding motion, with a scroll command (or vice versa). Accordingly, if the force measured by the force sensors **315** is over a threshold level of force, the input gesture may be interpreted as a click command. On the other hand, if the force measured by the force sensors **315** is less than the threshold level of force, the input gesture may be interpreted as a scroll command.

The touch-based user interface **300** may also include a displacement sensor that may derive spatial data relating to the position of the object on the interface, as well as proximity data relating to the distance of the object from the interface. In one embodiment, illustrated in FIGS. 4A-4C, the displacement sensor may be a capacitance sensor **320** that can detect the location of a finger (or other object) using mutual capacitance sensing. In one embodiment, the capacitance sensor **320** may be incorporated into the PCB layer **307** underlying the haptic feedback layer **301**. However, in another embodiment, the capacitance sensor **320** may be sandwiched between the haptic feedback layer **301** and the PCB layer **307**. In other embodiments, the capacitance sensor **320** may be incorporated into any layer of the touch-based user interface **300** described above, or may be an additional layer that is positioned above or below the other layers of the interface **300** or sandwiched between two layers of the interface **300**.

In one embodiment, the capacitance sensor **320** may include electrically conductive electrodes **335** that are deposited in varying patterns onto two flexible substrate sheets **331**, **333**. The substrate sheets **331**, **333** may be formed from a flexible, yet rigid nonconductive material, such as plastic, polyester, rubber, glass, and so on and so forth. In one embodiment, the electrodes **335** may be deposited on the inner surface of one sheet **331** to form a row pattern, and on the corresponding inner surface of the other sheet **333** to form a column pattern. The spacing between the rows **338** and columns **339** may vary according to different embodiments, with a smaller spacing size corresponding to a more sensitive capacitive sensor **320**. When the two substrate sheets are positioned with one on top of the other with the electrodes facing one another, a grid pattern may be formed. A finger, or other object, placed near the intersection **336** of two electrodes modifies the capacitance between them. This change in capacitance can be measured, and the position of the finger may be determined based on these changes at various points along the capacitance sensor.

In one embodiment, the piezoelectric actuators **100** may be embedded in the haptic feedback layer **301** so that the actuators **100** are aligned with the grid pattern formed by the electrodes **335** of the capacitance sensor **320**. For example, the piezoelectric actuators **100** may be positioned above the spaces **322** defined between the rows **338** and columns **339** of the grid so that the spaces **322** and the actuators **100** are aligned along at least one vertical axis. As a change in

capacitance is detected at a particular intersection **336** or group of intersections, a voltage may be supplied to the actuator **100** or group of actuators positioned proximate the intersections **336**. The piezoelectric actuators **100** may or may not be positioned above every space of the grid. For example, a single piezoelectric actuator **100** may be provided for every other space of the grid or every third space of the grid. In another embodiment, multiple piezoelectric actuators **100** may be provided for some spaces.

As discussed above, the haptic feedback from the piezoelectric actuators **100** may allow for enhanced navigation of the content displayed on a display coupled to the touch-based user interface. In one embodiment, the piezoelectric actuators **100** may replace the mechanical “click” of a mouse, trackpad, or other user interface of an electronic device. For example, the touch-based user interface may confirm a “click” by supplying a voltage to the piezoelectric actuators **100** so that the user feels a vibration or other motion. In one embodiment, the electronic device may interpret a tapping motion on the surface of the touch-based user interface as corresponding to a click command. In contrast, when the user glides a finger or other object along the surface of the touch-based user interface, the piezoelectric actuators **100** may remain unactuated. Accordingly, a user may be able to ascertain whether the electronic device has interpreted an input gesture as a click or a scroll.

In another embodiment, the piezoelectric actuators **100** may allow the user “feel” the selectable buttons or icons displayed by the electronic device. This embodiment may be particularly useful in a touch-based user interface that is not overlaid on a display screen, such as a trackpad or a mouse, in which the user cannot position a finger or other object directly over the displayed buttons and icons to select them. In one implementation, a voltage may be supplied to the piezoelectric actuators **100** when a cursor is positioned within selection range of a virtual button or icon. Accordingly, the user may feel a vibration or other motion indicating that the user may select the button with a selection input gesture.

FIGS. 5A and 5B illustrate a top down view and a perspective view of another embodiment of a touch-based user interface **200**. In this embodiment, the piezoelectric actuators **201** may take the form of one or more strands **203** that extend laterally across the haptic feedback layer **205**. In one embodiment, the strands **203** may be parallel to one another, and may extend in a horizontal direction across the haptic feedback layer **205**. In this embodiment, the electrically conductive traces connected to the strands **203** may be positioned on the sides of the haptic feedback layer **203**, as opposed to underneath the haptic feedback layer **203** as in the embodiment shown in FIGS. 3A and 3B. The strands **203** may be embedded in the nonconductive material **207** such that the strands **203** are exposed and form part of the outer surface of the haptic feedback layer **205**. Alternatively, the strands **203** may be covered by the nonconductive material **207**.

In other embodiments, the traces may be positioned underneath the strands **203**. In further embodiments, the strands **203** may not be parallel to one another, but may extend at angles with respect to one another. Additionally, the strands **203** may extend vertically or diagonally across the haptic feedback layer **205**, rather than horizontally.

FIGS. 6A-6C illustrate one embodiment of a method for manufacturing a haptic feedback layer. In a first step, illustrated in FIG. 6A, one or more piezoelectric actuators **100** may be arranged in a mold **160**. The mold **160** may define the shape of the formed haptic feedback layer. The

actuators **100** may be arranged in any configuration. For example, the actuators **100** may be evenly spaced apart in the mold **160**, or concentrated in one portion of the mold. The actuators **100** may have any shape. For example, the actuators may have a circular shape, a square shape, a triangular shape, or any other shape. The actuators may all be substantially identical, or some actuators may have a different configuration than other actuators.

In a second step, illustrated in FIG. **6B**, an adhesive **308** may be applied around all or a portion of the perimeter of the piezoelectric actuators **100**. As discussed above, the adhesive **308** may bind the piezoelectric actuators **100** to the nonconductive material. In one embodiment, the adhesive **308** may be a hot melt adhesive that is applied around the perimeter of the actuators. Other embodiments may use other types of adhesive, as discussed above. In an alternate embodiment, the adhesive **308** may be applied after the nonconductive material is added to the mold. For example, the actuators **100** may be spaced apart from the nonconductive material, and the adhesive may be added after nonconductive portion of the blank is formed. Additionally, some embodiments may not include an adhesive layer between the nonconductive material and the piezoelectric actuators **100**. Accordingly, the adhesive application step described above is optional.

In a third step, illustrated in FIG. **6C**, a nonconductive material **311** may be added to the mold to fill the spaces between the piezoelectric actuators **100**. In one embodiment, the nonconductive material **311** may be heated to a liquid form and then poured into the mold **160** to fill the spaces between the actuators **100**. In another embodiment, the nonconductive material **311** may be added to the mold **160** in solid form, and the actuators and the nonconductive material may be heated to melt the nonconductive material **311** so that it fills the spaces between the actuators **100**. After the nonconductive material **311** is added to the mold **160**, the composite layer may be heated, baked, or otherwise processed to form the final haptic feedback layer **301**.

In one embodiment, both the nonconductive material and the actuators may each define a portion of the outer surface of the haptic feedback layer. However, in other embodiments, the nonconductive material **311** may cover all or part of the actuators **100** to form one or more of the side, top and/or bottom surfaces of the haptic feedback layer. Accordingly, in one embodiment, the nonconductive material may define the outer surfaces of the haptic feedback layer, or the actuators may define a portion of one outer surface of the haptic feedback layer, while the other surfaces are defined by the nonconductive material.

FIGS. **7A-7C** illustrate another embodiment of a method for manufacturing a haptic feedback layer. In particular, FIG. **7A** illustrates a perspective view of a composite blank **700** that may be used to form a haptic layer of a touch-based user interface. As shown in FIG. **7A**, the composite blank may include one or more piezoelectric strands **201** that are conjoined with a nonconductive material **311**. The strands **201** may have any cross-sectional configuration. For example, the strands may have a circular cross-section, a rectangular cross-section, a square cross-section, a triangular cross-section, and so on and so forth. In one embodiment, the piezoelectric strands may be parallel to one another such that the strands form one or more rows and one or more columns within the composite blank. However, in other embodiments, the piezoelectric strands may extend at angles from one another. As discussed above, the side surfaces of the piezoelectric strands may be joined to the nonconductive material by an adhesive material **308**.

The composite blank **700** may be formed in a manner similar to that described with respect to the method for forming a haptic layer illustrated in FIGS. **6A-6C**. That is, the composite blank **700** may be formed by arranging the piezoelectric strands **201** in an array configuration, and then filling the spaces between the strands with a nonconductive material **311**. The array of strands may first be arranged in a mold defining the shape of the blank.

As discussed above, the spaces between the strands of the array may then be filled with the nonconductive material **311**. In one embodiment, the nonconductive material **311** may be heated to a liquid state, and then poured over the array of piezoelectric strands **201**. In other embodiments, the nonconductive material, in solid form, may be placed around the piezoelectric strands, and the strands and the nonconductive material may be heated so that the nonconductive material is melted and fills the gaps between the strands. In one embodiment, adhesive **308** may be applied to the side edges of the strands before the nonconductive material is added to the mold.

The formed composite blank **700** may then be cut to form different configurations of touch-based user interface devices. In one embodiment, shown in FIG. **7B** the blank may be cut along a plane perpendicular to the direction of extension of the strands to form a haptic feedback layer **301** similar to that shown in FIGS. **3A** and **3B**, with the shape of the piezoelectric actuators **100** varying according to the cross-sectional profile of the strands **201**. The blank may be cut using, for example, a computer-numerical controlled laser cutting tool, or alternatively, a mechanical cutting tool such as a blade. In another embodiment, shown in FIG. **7C**, the blank **700** may be cut along a plane parallel to the direction of extension of the strands **201** to form a haptic feedback layer **205** similar to that shown in FIGS. **5A** and **5B**. For example, the blank may be cut along the nonconductive areas between the strands so that the piezoelectric strands of the resulting touch-based user interface are covered by the nonconductive material. Alternatively, the blank may be cut to expose the strands **201** so that the strands form at least part of the outer surface of the resulting haptic feedback layer **205**.

FIG. **8** is a flowchart illustrating one embodiment of a method **800** for manufacturing a haptic feedback layer. For example, the illustrated method **800** may be used to form an embodiment similar to that shown in FIGS. **3A** and **3B**. The method **800** may begin by arranging one or more piezoelectric actuators in a spaced-apart configuration, as indicated in block **801**. As discussed above, the mold may define the shape of the formed haptic feedback layer. The actuators may be arranged in any configuration. For example, the actuators may be evenly spaced apart in the mold, or concentrated in one portion of the mold.

An adhesive may then be applied around at least a portion of the perimeter of the piezoelectric actuators, as indicated in block **803**. As discussed above, the adhesive may bind the piezoelectric actuators to the nonconductive material. In some embodiments, the adhesive may have a high modulus of elasticity so as to allow the piezoelectric actuators to move relative to the nonconductive material while resisting debonding of the actuators and the nonconductive material, as well as cracking or wear of the adhesive itself.

The spaces between the actuators may be filled with a nonconductive material, as indicated in block **805**. As discussed above, in one embodiment, the nonconductive material may be heated into liquid form and poured into the mold to fill the spaces between the actuators. In other embodiments, the nonconductive material may be inserted into the

## 13

mold in solid form, and the actuators and the nonconductive material may be heated so that the nonconductive material fills the spaces between the actuators.

FIG. 9 is a flowchart illustrating another embodiment of a method 900 for manufacturing a haptic feedback layer. For example, the illustrated method 900 may be used to form embodiments similar to that shown in FIGS. 3A and 3B and FIGS. 5A and 5B. The method 900 may begin by arranging one or more piezoelectric strands in a spaced-apart configuration, as indicated in block 901. As discussed above, the spacing between the strands and the configuration of the strands may vary according to different embodiments. The strands may first be arranged in a mold defining the shape of the blank. The spaces between the strands may then be filled with a nonconductive material to form a composite blank, as indicated in block 903. As discussed above, the nonconductive material may be heated into liquid form and poured into the mold to fill the spaces between the strands. In other embodiments, the nonconductive material may be inserted into the mold in solid form, and the strands and the nonconductive material may be heated so that the nonconductive material fills the spaces between the strands.

The composite blank may then be cut, as indicated in block 905. As discussed above, in one embodiment, the composite blank may be cut along a plane perpendicular to the direction of extension of the strands. In another embodiment, the composite blank may be cut along a plane parallel to the direction of extension of the strands so that the formed haptic feedback layer includes one or more strands extending across it. The strands may be exposed, so that the strands form a portion of the outermost surface of the haptic feedback layer, or may be covered by the nonconductive material.

The order of execution or performance of the methods illustrated and described herein is not essential, unless otherwise specified. That is, elements of the methods may be performed in any order, unless otherwise specified, and that the methods may include more or less elements than those disclosed herein. For example, it is contemplated that executing or performing a particular element before, contemporaneously with, or after another element are all possible sequences of execution.

The invention claimed is:

1. A touch-based user interface, comprising:
  - a haptic feedback layer comprising a layer of nonconductive material and one or more actuators embedded within the layer of nonconductive material, the one or more actuators configured to supply a haptic feedback; one or more force sensors configured to differentiate among a plurality of input commands based, at least in part, on an amount of force sensed by the one or more force sensors; and
  - a printed circuit board layer, disposed on a first side of the haptic feedback layer, and positioned between the haptic feedback layer and the one or more force sensors, the printed circuit board layer including one or more conductive traces configured to supply a voltage to the one or more actuators, wherein
  - a second side of the haptic feedback layer opposite to the first side is positioned toward an outermost surface of the touch-based user interface.
2. The touch-based user interface of claim 1, wherein at least one of the one or more actuators is a piezoelectric actuator.
3. The touch-based user interface of claim 1, wherein the printed circuit board layer further comprises a capacitive sensor.

## 14

4. The touch-based user interface of claim 3, wherein the capacitive sensor includes a first layer of electrodes and a second layer of electrodes, the first layer of electrodes overlaying the second layer of electrodes to form a grid defining one or more spaces between the first layer of electrodes and the second layer of electrodes.

5. The touch-based user interface of claim 4, wherein at least one of the one or more actuators is aligned along at least one vertical axis with at least one of the one or more spaces of the grid.

6. The touch-based user interface of claim 1, wherein the one or more force sensors are positioned underneath the printed circuit board layer.

7. The touch-based user interface of claim 1, wherein the one or more actuators forms at least a portion of an outer surface of the haptic feedback layer.

8. The touch-based user interface of claim 1, wherein the one or more actuators is joined to the nonconductive material by an adhesive.

9. The touch-based user interface of claim 1, wherein at least one of the one or more actuators is configured to move independently from another actuator of the one or more actuators.

10. The touch-based user interface of claim 1, wherein the one or more actuators form rows of actuators that extend laterally across the haptic feedback layer.

11. The touch-based user interface of claim 1, further comprising a cover layer overlaying the haptic feedback layer.

12. The touch-based user interface of claim 1, wherein the nonconductive material has a modulus of rigidity to prevent the nonconductive material from moving relative to the one or more actuators when a voltage is supplied to the one or more actuators.

13. A method for manufacturing a haptic feedback layer, comprising:

- arranging one or more piezoelectric actuator strands so that each of the one or more piezoelectric actuator strands are spaced apart from one another;
- melting a nonconductive material to form a liquid;
- filling spaces between the piezoelectric actuator strands with the melted nonconductive material to form a blank so that the piezoelectric actuator strands are embedded within the nonconductive material;
- cutting the blank to form a haptic feedback layer;
- orienting one side of the haptic feedback layer toward a first side of a printed circuit board layer; and
- coupling one or more force sensors to a second side of the printed circuit board layer that is opposite to the first side, wherein the one or more force sensors are configured to differentiate among a plurality of input commands based, at least in part, on an amount of force detected by the one or more force sensors.

14. The method of claim 13, wherein the blank is cut along a plane perpendicular to a direction of extension of the piezoelectric actuator strands.

15. The method of claim 13, wherein the blank is cut along a plane parallel to a direction of extension of the piezoelectric actuators strands.

16. The method of claim 15, wherein the blank is cut such that only the nonconductive material between the piezoelectric actuator strands is cut.

17. A touch-based input device, comprising:
- one or more actuators embedded within a layer of nonconductive material and configured to supply a haptic feedback; and

one or more force sensors embedded within a printed circuit board layer and configured to differentiate among a plurality of input commands based, at least in part, on an amount of force sensed by the one or more force sensors;

5

wherein the printed circuit board layer is attached to the layer of nonconductive material and comprises one or more conductive traces that supply a voltage to the one or more actuators, and the layer of nonconductive material is positioned toward an outermost surface of the touch-based user interface.

10

**18.** The touch-based input device of claim **17**, wherein the outermost surface of the touch-based input device is configured to flex in response to a received force.

**19.** The touch-based input device of claim **17**, wherein a first input command of the plurality of input commands is associated with a first gesture and a second input command of the plurality of input commands is associated with a second gesture.

15

**20.** The touch-based user interface of claim **4**, wherein the capacitive sensor measures a change in capacitance at a location at which a first electrode of the first layer of electrodes crosses above a second electrode of the second layer of electrodes.

20

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25